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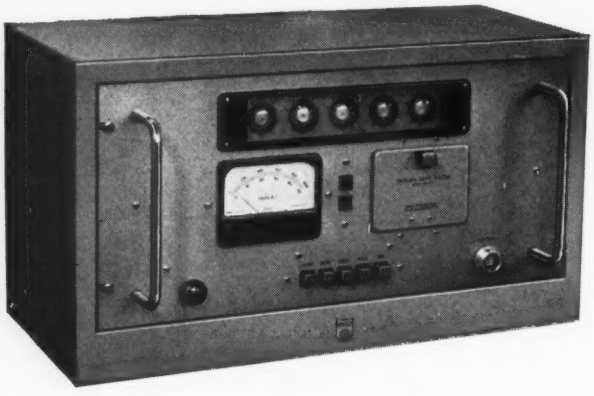

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NUCLEAR ENGINEERING VOL. I NO. 5 AUGUST, 1956

EDITORIALS

Second Year of the U.K.A.E.A.

IN accordance with section 3 (5) of the Atomic Energy Act, 1954, the second annual report of the United Kingdom Atomic Energy Authority was submitted to Parliament on July 25. A summary is given on pages 191 and 192 of this issue. The report speaks of the great increase of interest and activity both in this country and overseas in atomic energy developments and points out that whereas a year ago nuclear power appeared for most countries to be a possibility in the remote and indefinite future it is a matter now not of conjecture but of dates and comparative costs. One of the most significant impressions given at the World Power Conference in Vienna in June came from British delegates who were able not merely to discuss design studies and possible reactor systems but were able to speak in terms of firm quotations for large power reactors available from each of four groups of companies. The ability of industrial companies in this country to make firm quotations for nuclear power stations has come as a surprise to many electricity authority undertakings.

For the first time the report acknowledges the potential export market in the reactor field and outlines the attitude expressed by Mr. Butler in replying to questions in Parliament when he stated that Her Majesty's Government were fully alive to the importance of the export of nuclear reactors and components by British industry, but immediate opportunities lay in the export of research reactors for which some orders have already been secured. The report suggests that orders for power reactors from overseas countries will await the completion of the first stations at Bradwell and Berkeley. At present British companies have received either inquiries or firm orders for a research reactor in Australia and two in Germany. The interest, however, expressed by Japan in the graphite-moderated, gas-cooled reactor may bring about a change in the official attitude and although it is unlikely that any company will receive a contract for a complete nuclear station other than from electricity authorities in the United Kingdom in the next few months there is every likelihood that at least one will have been received before the scheduled date of completion of the first C.E.A. stations.

Discussion on experiments being undertaken to determine the feasibility of utilizing the thermo-nuclear reaction for power production has been disappointing. The attitude of the Authority over this question is in direct contradiction to the statement that steps have been taken during the past year to release from security's restriction virtually the whole of the basic information needed in a research and development programme for the peaceful application of atomic energy. The continued silence on this topic is undoubtedly lending a false importance to developments in this field. On purely general grounds it can be deduced that the construction of a reactor to generate power by fusion will involve considerable technological problems and it will be very many years before a simple system can be worked out. In fact it is probable that even ultimately cost of plant and equipment to build a fusion power station will be of the same order as for a fission station with maintenance costs also similar, and the significance, therefore, of the project lies only in the availability of the raw materials. At present there is no suggestion that uranium or thorium will be in short supply within the foreseeable future and with improving extraction techniques the detailed fuel costs must be expected to fall appreciably over the course of the next few years. Even if a major technological breakthrough has been made—a phrase which seems to be used almost solely in connection with the thermo-nuclear field—apart possibly from the prestige point of view little purpose is served by witholding information on at least the state of the present research programme. Even if there is nothing to be said this should be officially announced.

Following the Calder Hall type, choice of reactor for a stage 2 development, if this should be considered desirable, may fall on the graphite moderated, sodium cooled enriched uranium reactor. This type has the advantage of requiring only pumping pressures in the coolant system for outlet temperatures in the region of 500°C. A considerable amount of work has been done on the compatability of sodium with suitable sheathing materials and means of preventing penetration of the graphite pores. It is probable that a combination of zirconium cladding and sealing would be used. Demands for hafnium-free zirconium are likely to become considerable if this type of reactor system goes into production. The experience gained by many companies throughout the country on sodium loops will ensure a fair measure of industrial experience in the application of techniques should the prototype come to be built.

Of considerable significance in the comments on the pressurized water system is the possibility of substituting di- or terphenyl for the water. The advantages of lower pressures, compactness of design, and less stringent corrosion problems make this type an attractive proposition if degradation of the moderator can be controlled. No doubt the OMRE project in the U.S.A. has encouraged a more progressive attitude towards the system.

The list of reactors considered for stage 3—the fast reactor, the homogeneous aqueous reactor, the liquid metal fuelled reactor and the high temperature gas-cooled reactor contains no surprise items. It brings the total to eight types under examination or in production and makes the U.K. selection identical with the published U.S. programme. Canada is alone in actively considering a heavy water system, and only Holland has yet announced plans for a more exotic type such as a fluidized fuel reactor. Such designs are nevertheless receiving at least theoretical considerations.

Europe's Energy Problem

THE O.E.E.C. report prepared by a group of experts under the Chairmanship of Sir Harold Hartley* on Europe's growing needs of energy is a well written and well presented document covering the whole range of fuel and power in Western Europe. The terms of reference of Sir Harold Hartley's Commission originated from an earlier O.E.E.C. report by M. Louis Armand, Chairman of the Société Nationale des Chemins de Fer Français, who concluded that the energy economy of Western Europe was entering on a new phase and recommended the appointment of a group of experts to examine the whole energy field and particularly the effect of nuclear power on future energy economy in order that member countries might be made aware of the new problems which they have to face.

For convenience in presenting the over-all energy picture, and for making comparison between one source and another, all energy quantities are expressed in terms of an equivalent tonnage of coal. The inland consumption of primary energy in the O.E.E.C. area estimated for 1955 is made up as follows (from Table 2)—

1955 Consumption of energy in million tons of coal equivalent

Coal	511
Lignite	31
Hydro-power	57
Natural gas	5
Crude oil	126
Total	730

Forecasts are given in the report of the total primary energy consumption in the years 1960 and 1975. These are summarized in Table 5 which is reproduced below—

Forecasts of energy consumption in million tons of coal equivalent

	1955 base year	1960	1975
Maximum		860	1,300
Mean	730	840	1,200
Minimum		820	1,100

The indigenous production of primary energy in the O.E.E.C. area has been assessed for the year 1955 and is forecast for the years 1960 and 1975. These production figures are summarized in Table 6 as follows—

Indigenous production of energy in million tons of coal equivalent

	1955	1960	1975
Coal	478	500	520
Lignite	31	35	35
Hydro-power	57	75	130
Crude oil	13	25	50
Natural gas	5	10	20
Total	584	645	755

In the year 1955 the gap between indigenous production and the consumption of primary energy was filled by the net import of 29 million tons of coal and of 84 million tons of crude oil and petroleum products, involving an expenditure equivalent to 1,900 million dollars. The gap which amounted to 146 million tons of coal equivalent in 1955 is estimated (taking the mean forecast from Table 5) to rise to 195 million tons in 1960 and to 445 million tons by 1975.

The contribution to be expected from nuclear energy by 1975 is discussed in the Report in the following terms—

"The future energy prospects of the world have been altered fundamentally by the possibility of utilizing nuclear power, without which these prospects might now be looking rather gloomy in view of the limits of other resources. The supplies of nuclear fuels have multiplied the capital reserves of energy many times, and the concentrated nature of nuclear fuels will reduce their transport costs to any point in the world to a small fraction of the cost for conventional fuels.

"In the absence of definite long-term plans from the other Member countries, we have taken as a basis the estimate made by the United Kingdom that nuclear power stations in the United Kingdom will produce in 1975 the equivalent of 40 million tons of coal. After consulting various authorities and taking into account official reports from the United States, we regard as a reasonable forecast an equal production from other nuclear power stations in Western Europe in 1975. The rate of progress will depend on the co-operation between the countries concerned.

"If our forecast is correct, nuclear energy is unlikely to provide more than 8% of the total energy demand in Western Europe in 1975. No doubt after 1975 the output from nuclear reactors should increase rapidly, but our forecast indicates that it is a mistake to assume that atomic energy on a large scale is just round the corner."

This is certainly a sobering statement, and on a first reading the report may appear to discount the importance of nuclear energy altogether, but it must be remembered that the report is concerned with the total needs of energy in all its different forms. Nuclear energy can only be applied at present in the production of secondary energy in the form of electricity. If we take the forecasts of production of electrical power in 1960 and 1975 we have the following figures from Table 8 of the report—

Production of electrical power in 1960 and 1975 (in TWh†)

	1955	1960	1975	
			low	high
Hydro production	140	185	300	350
Nuclear production	—	—	200	200
Thermal production	210	295	550	850
Total production	350	480	1,050	1,400

In absolute magnitude, therefore, the scale envisaged for nuclear production of electricity in 1975 is very substantial indeed. Taking the figure of 200 TWh per annum (or the equivalent of 80 million tons of coal) nuclear power stations are expected to provide by 1975 an annual output of electrical energy almost as great as the present annual output from existing thermal stations in the O.E.E.C. area.

It is of interest then, to consider the way in which nuclear power will be developed technically in Western Europe during the first stage between now and 1975. The United Kingdom programme has been clearly stated and will be based in the first phase on the construction of a relatively large number of graphite-moderated gas-cooled reactors fuelled with natural uranium. The programme envisages the possibility of other types of reactor being built for power generation when enrichment of fuels becomes possible with the use of by-product plutonium. It is quite probable, however, that the graphite-moderated gas-cooled natural-uranium reactor may become so well established and so well developed in its engineering detail that it will be many years before it is seriously threatened by any rival design. It is certainly a great mistake to assume that other types of reactor are necessarily more "advanced" than the graphite-moderated gas-cooled type.

If a substantial contribution is to be made from nuclear sources to Europe's energy requirements by the year 1975, and in spite of the disclaimers the report of the Hartley Commission does in fact assume the substantial figure of 200 TWh in 1975, it would seem that a start should be made at once on the continent of Western Europe with the construction of a number of nuclear reactor power plants designed to use natural uranium for their fuel. Indeed the fuel and power problem on the Continent, although not perhaps quite so pressing as the same problem in the United Kingdom, has so many features in common that it would be very surprising if the Continental members of O.E.E.C. did not find their interests best served by pursuing a course parallel to that of the United Kingdom in the nuclear energy field.

* "Europe's Growing Needs of Energy. How can they be met?" Organization for European Economic Co-operation, Paris.
† 1 TWh = 1 Terawatt-hour = 1,000 million kWh.

Comments on the News

ATOMIC POWER FOR NORTHERN IRELAND

The White Paper—"Electricity Supply in Northern Ireland" Cmd. 355, H.M.S.O., Belfast—published by the Government of Northern Ireland marks a very significant step along the path towards the normal commercial application of nuclear energy for electricity generation. Here is a small country, relatively highly developed both in its agriculture and in its industries, but lacking any indigenous supply of fuel and having only limited resources of water power. The cost of importing coal and oil is high and the Province might therefore be regarded as an ideal region for the application of nuclear energy.

There is one very important difference, however, between the situation in Northern Ireland and the corresponding development of nuclear power for electricity generation in Great Britain. Whereas the installed capacity of generating plant in the stations of the Central Electricity Authority in England and Wales is approximately 20,000 MW, the total installed capacity in Northern Ireland at present amounts to only 391 MW. If a nuclear power station is to be an economic proposition it must be built for a relatively large power output and must be operated at high load factor. A nuclear power station of 200 MW electrical output would represent only a very small proportion of the total generating capacity of the C.E.A.; there would be no difficulty in operating such a station on base load duties at high load factor, and there would be sufficient stand-by plant available to cover any teething trouble with the nuclear station during the early period of its operation. In Northern Ireland, however, a nuclear station of 200MW would represent a very large proportion even in the mid-1960's when the total installed capacity required in the Province may be 700 or 800 MW. It would certainly be necessary for a nuclear station to be regarded as providing "firm power" almost from the date of its commissioning. It would also be necessary for nuclear generating plant to be capable, to some extent at least, of following a varying load demand.

It is stated in the White Paper that, because of this, and because of the uncertainties still existing about the final design and economics of the early nuclear stations, the conclusion has been reluctantly reached that it would not be feasible to meet the immediate need for additional generating capacity, foreseen as being required about 1960, with an atomic station. It is recognized, however, that these difficulties are only temporary and the important statement is made that the Government is proceeding on the basis that "after providing for the needs for 1959-60 and immediately thereafter, the establishment of an Atomic Station should be considered as a desirable development at the earliest stage at which it can reasonably be expected to be advantageous. To this end, the Electricity Board for Northern Ireland has been asked and has undertaken, in consultation with the Ministry's Consultants, to make such preliminary plans and arrangements as will expedite the establishment of a Station as soon as the time for its establishment is determined."

The programme presented in Part III of the White Paper is of special interest. After the works now in progress at Belfast Station West have been completed the available generating capacity in the Province will be overtaken by the growth of the load by 1960-61, and if nothing more were done the deficiency would grow to more than 100MW by 1962-63. It is observed that, to proceed now with the establishment of a new major conventional station, which would provide the power required over the following five or six years, would be to defer the possibility of introducing atomic power further than present knowledge and expectations in that field would justify. A limited programme has therefore been adopted to meet the pressing needs of the two years 1960-62. This limited programme includes the construction of a new conventional thermal power station at Londonderry of 60 MW capacity, the extension of the 110 kV transmission system, and the possible installation of an additional 30 MW generator at the existing Ballylumford station. For the second stage of the programme it is hoped that it may become possible to establish a major atomic station to come into operation by 1963-64, and to be subsequently expanded in successive years. "Starting with a capacity of 200 MW, with two generators of 100 MW each to come into operation in successive years, expansion to double this capacity would, on the present estimates of demand, provide sufficient power up to about 1969."

Assuming that this programme is carried through to a successful conclusion, Northern Ireland will be in the unique position by 1969 of having an electricity system with approximately 4% of its total generating capacity represented by nuclear plant. The actual proportion of the electrical energy in kilowatt-hours derived from the nuclear plant would of course be larger since the nuclear station would be operating at higher load factor than the other thermal stations. In these circumstances Northern Ireland would be able to claim the distinction of being the first country in the world to adopt nuclear energy as its main source of power.

WORLD POWER CONFERENCE

Contrary to the report on this page in the July issue of *Nuclear Engineering*, the World Power Conference held in Vienna from June 17-23 was the fifth plenary session. In addition to the plenary meetings, the organization has held eight sectional meetings. Three papers on atomic energy were presented at the Fuel Economy Conference held at The Hague at a sectional meeting of the World Power Conference in 1947, and five papers on atomic energy were submitted in section "J" at the fourth World Power Conference held in London in 1950. The papers presented on the Calder Hall and Shippingport projects are, however, the first in the series to cover power reactors under course of construction.

The organization of the Conference was in marked contrast to that of the American Nuclear Society in Chicago. In Vienna copies of papers were required for translation and preprinting many months before the date of presentation, and as a result much of the material included represented only a small advance on the information published at the Geneva Conference last year. In Chicago, no preprints were available of the papers to be submitted and contributors had been asked to present up-to-date information on projects with which they were directly concerned, to be followed by a comprehensive discussion. In some instances contributors were able to give accounts of experiments conducted only the week previous to the Conference, and a considerable amount of new information was released. As a result discussion was spontaneous and concerned directly with papers submitted. On the other hand, at Vienna not only were copies of the papers required prior to the date of the Conference, but comments also on these papers were required in triplicate at least two days before the submission of the paper. As a result most of the discussion periods were occupied by delegates reiterating material which had already been published, perhaps in another session and frequently on a subject not

directly connected with that of the paper. The power programmes of a number of countries were repeated on a number of occasions during the dicussion periods.

The limitations of a highly formalized organization are clear, and apart from assembling a large number of scientists and engineers in one town at the same time, the Conference itself served little useful purpose over and above that which will be served by the publication of the individual papers and comments. At the same time, in Chicago 180 papers were submitted in the course of a few days and visitors to the Conference were required to exercise a considerable measure of discrimination in the sessions they could attend, and had to rely largely on the titles of the papers and very short synopses to guide them in their choice. As a result a number of papers of significance were ill-attended and all were inevitably missed by some who would have wished to take part. Furthermore, there is no record of the proceedings of this Conference, and although some of the information will be disseminated through the Press over the following months, much of the material will inevitably be lost.

The need, therefore, in this conferences is for a compromise between the two systems. The total number should be limited and papers should be submitted a few weeks before the conference and only additional information given during the sessions. The remainder of the time should be left open to free discussion. It is the responsibility of the chairman to ensure that only a relatively narrow field is covered by the comments. Material published on the conference requires to be edited energetically in order to compress the useful parts of the discussion into a minimum of space.

WESTERN REACTOR PROGRAMMES

Some misconceptions have arisen out of a statement by Sir John Cockcroft at Lindau in West Germany, where he has been reported as stating that Britain should concentrate on gas-cooled reactors, the United States on water-cooled reactors and Canada on reactors cooled by heavy water. The inference has been taken that this state of affairs should be formalized and that the individual countries concerned should concentrate more or less solely on the types specified. In fact Sir John reported that developments in the three countries have proceeded on lines where the United States is concentrating on the water-cooled reactor, the United Kingdom on the gas-cooled and Canada on the heavy water, and that this was a desirable state of affairs with these three powers carrying out their intensive research on different reactor systems. There was no suggestion that the three countries should formally agree to divide the reactor field neatly into three parts, and although it appear possible that stage two in the United Kingdom's power reactor programme will be a sodium-cooled, graphite-moderated reactor rather than a pressurized water reactor, the decision has been taken for technological and economic reasons. The same applies to the heavy water reactor, which Sir John described as a promising reactor of the future but if adopted would require a supply of 1,000 tons of heavy water a year to the United Kingdom, which would imply a very large development scheme which this country cannot at present undertake.

THE U.K. AND EUROPE

The attitude of the United Kingdom towards European co-operation in the field of atomic energy with regard to the O.E.E.C. scheme and the Euratom scheme has been clarified by a statement to the ministerial council of the Organization for European Economic Co-operation in Paris. Britain, it was stated, would probably be prepared to co-operate in the construction of an international chemical treatment plant, but was not interested in assisting other countries to build a gaseous diffusion plant or to manufacture heavy water. The statement was made during a discussion on further O.E.E.C. plans for co-ordinating European effort in which the resolution was made that energetic steps would be taken towards the pooling of resources and the setting up of a European atomic agency. A steering committee within the framework of O.E.E.C. is to be set up to prepare within six months a charter for a European nuclear energy agency. The special committee whose report has been under consideration has also recommended that O.E.E.C. should encourage groups of member nations to co-operate in the building of a gaseous diffusion plant, a heavy water plant and a chemical separation plant, and although not all countries will be interested in all projects, the individual groups should be encouraged to go ahead independently. Freezing of tariffs and import duties on nuclear materials is also included in the scheme. The six member nations in the Euratom scheme have all expressed certain reservations to their full acceptance of the O.E.E.C. scheme, but it is considered that there should be no difficulty now in linking up the two organizations to the satisfaction of both parties. Sir Edward Boyle, economic secretary to the treasury, is quoted as explaining Britain's attitude in the light of her experience with the New Zealand heavy water project, the offer of the United States to supply enriched fuel and the fact that Britain has been engaged on atomic energy research for nine years, whereas the majority of the countries in the European agency are only just beginning to be interested in the atomic field.

FUNDAMENTAL PHYSICS

Whilst confirmation of the existence of the anti-proton and the neutrino have lent strength to the existing theories of the structure of matter, it has become increasingly clear over the past few years that the quantum and relativity theories are no longer fully adequate to explain physical phenomena. Professor Heisenberg of Germany and Professor Yukawa of Japan have stated that these theories could now only explain part of the revolutionary discoveries of nuclear science in the past decade. The existing theories at best serve to give a semi-phenomenological explanation for the qualities of elementary particles, and they fail to explain their existence convincingly. Professor Heisenberg is heading a team of German professors at the Max Planck Institute, who are drafting an expanded and remoulded version of the quantum theory with which he hoped a better understanding of the masses and interactions of elementary particles could be reached. Professor Yukawa expressed the view that in future one would start from an overall space time picture of elementary particles and then derive causal relationships between the phenomena which are more or less localized. Extrapolation of existing theories had progressed so far that it would not be useless to reconsider the whole subject from an entirely different standpoint, and a complementary approach, although difficult, as it implies leaving the firm, well-established space-time structure, would give some help to future progress. This view is apparently echoed in most of the countries with research organizations working on the fundamental structure of matter.

OUR ATOMIC WEATHER

The almost unanimous opinion of the Nobel prize-winners' international conference that the atomic bomb tests have no effect on the weather will probably carry little weight with the bulk of the population, who are always anxious to find a scapegoat for the inclement weather normally obtaining in the United Kingdom. Developments in atomic energy have carried the responsibility for the English summer for some years past, and it would be unreasonable to suggest that the attitude of the experts should be allowed to deprive the public of such a regular topic of conversation. Rather must one expect that the results of future test matches will be ascribed to the statistics of coin tossing and the frequency of atomic bomb explosions.

Australian A.E.C. Research Programme

by

C. N. WATSON-MUNRO, O.B.E., A.M.I.E.E., F.Inst.P.

Chief Scientist, Australian Atomic Energy Commission

After a study of work being done in other countries the A.A.E.C. decided that its attention could most profitably be devoted to feasibility studies of the gas-cooled impregnated moderator fuel element type and liquid-metal cooled reactors. To this end the research station at Lucas Heights is to have a high-flux experimental reactor similar to DIDO.

THE Australian Atomic Energy Commission was constituted in April, 1953, with Sir Jack Stevens as chairman, Professor J. P. Baxter as deputy chairman and H. M. Murray, member. It has two main fields of activity[1]:—

1. That related to the discovery and development of Australia's uranium and other special nuclear material resources.
2. That related to the development of the uses of atomic energy for industrial purposes. This second function includes not only the research work being undertaken by the Commission's own laboratories, but also relations with the Universities and with Australian industry.

Whilst a number of the present staff of the Commission was engaged during the war in senior capacities in atomic energy developments in North America, and in the post-war period in Great Britain, the first official steps by the Australian Government were taken in 1947 when a group of about twelve Australian scientists were seconded to work at the Atomic Energy Research Establishment at Harwell.

In 1954 arrangements were made with the U.K.A.E.A. for an interchange of information in the general field of reactor technology and for additional Australian scientists to work in the U.K.A.E.A. laboratories pending completion of laboratory facilities in Australia. These arrangements, coupled with the considerable experience gained by some staff during the past decade has enabled Australia to begin her programme at an advanced level of technology and to avoid repetition of much of the early work in the development of atomic energy.

Late in 1954 Government approval was given for the the Sydney area at an initial capital cost of A£5½ million, including a modern research reactor. An initial research establishment of 400 is proposed; including 50 senior scientists, all of whom have now been recruited.

Research Programme

Until laboratories are available, arrangements have been made for the initial investigations of the research programme to commence in Australian Universities and at the U.K.A.E.A. Research Establishment at Harwell.

In formulating its research programme the A.A.E.C. has been guided by the following factors:—

1. Australia has entered the field at a relatively late stage, and with her limited resources it would be unwise to attempt to develop the kinds of power reactors that have received major attention overseas and are in an advanced stage of pilot model construction; particularly as Australia will have access to the results of much of this work as it develops overseas.
2. Whilst the possibilities of air cooled condensers are appreciated, Australia, with her shortage of cooling water in many parts of the continent, has a special interest in reactors that are basically capable of development to gas turbine-temperatures of above 650°C; moreover this is a field where thermodynamic efficiencies are higher and not a great deal of world effort has yet been applied.
3. Any reactor system selected should be able to be taken to the reactor experiment stage with Australian resources. This criterion, particularly when viewed in the light of the current U.K. and U.S.A. experiments on fast breeder reactors, rules out a fast reactor at least in the early stages of the Australian programme.

An examination of thermal reactor systems shows a choice of:—

Moderator	*Coolant*	*Fuel*	*Fuel Cycle*
Graphite	Gas	Gas	Natural Uranium
Beryllia	Liquid Metal	Oxide or	U 233-Th Converter
Beryllium	Fused Salt	Carbide	Pu Breeder
Fused Salt	Organic Liquid	Suspension	
Organic Liquid	D_2O	or Slurry	
D_2O	H_2O	Solution	
H_2O		Metal	
in descending order of temperature	in descending order of temperature	(Canned)	

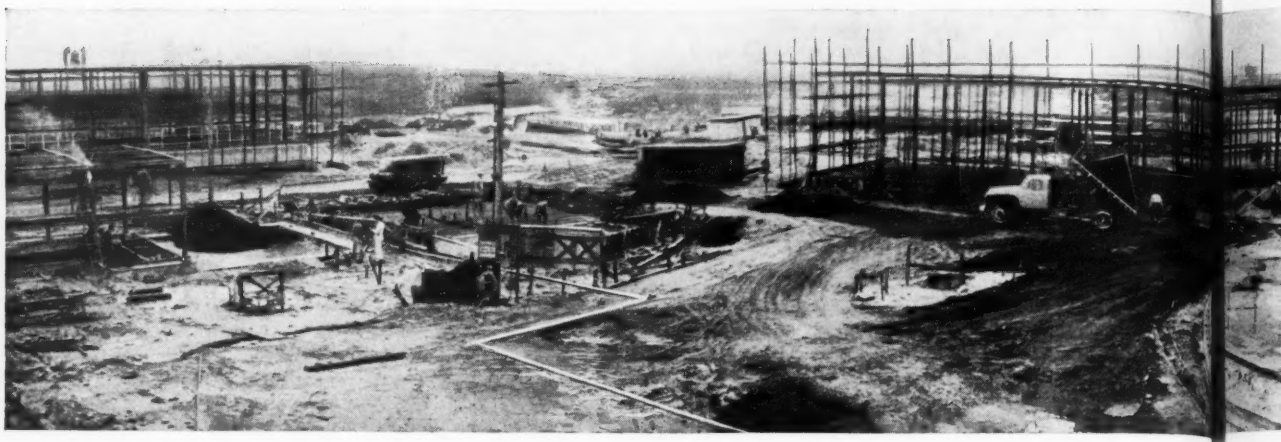
The criterion of high temperature operation necessitates the use of graphite, beryllia or beryllium as a moderator and a gas or a liquid metal as a coolant. When the other factors were taken into account we concluded that, initially, Australia could most profitably devote her attention to feasibility studies of the following systems:

1. A gas-cooled impregnated moderator fuel element type of reactor. This type of reactor can be shown to

Pond under construction in the active area building

Laboratories

Offices and laboratory building



Panoramic view of the Lucas Heights site, June, 1956.

Delay tank site

have possibilities for electrical outputs from 10 MW to a base load station of 200 MW.

2. Liquid-metal-cooled reactors, where the liquid metal is used as fuel carrier.

In both cases it is proposed to employ a thorium-U 233 conversion cycle.

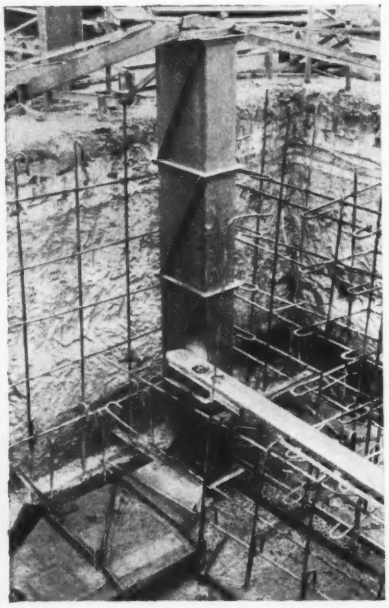
Some preliminary calculations have shown that a gas-cooled impregnated moderator type of reactor gives promise if a high-flux fuel element can be developed.

In the liquid metals field we are studying the considerable amount of work which has been undertaken by the Brookhaven National Laboratories using a solution of uranium in bismuth. We are also investigating the possibilities of sodium as a coolant-fuel carrier and beryllium as a moderator. Work is proceeding at the laboratories in Sydney on the construction of a sodium loop and small scale studies have commenced on the manufacture of a sodium-uranium suspension with particles of diameters of less than 10 microns. An extensive series of compatibility experiments with beryllium and fission products is also planned in the preliminary steps of the development of the A.A.E.C. research programme.

An analysis of the problems remaining to be solved in the systems discussed indicates that the majority of the difficulties lie in the field of the behaviour of materials under irradiation and at high temperatures and the economic processing of the reactor products. With this in mind the emphasis on buildings and facilities at Lucas Heights has been towards providing high neutron fluxes, methods of examining irradiated samples and loops, fabrication of special nuclear materials and, in fact, a general bias towards the metallurgical and engineering services.

Facilities Under Construction

A site of 160 acres has been selected in a Government-held reserve area some five miles from the southern outskirts of Sydney. A constructional contract was let in October, 1955, and the work of clearing the site, road preparation and building foundations is well advanced. The initial efforts are being concentrated on the reactor group of buildings. Designs are complete for an active effluent system with monitored delay tanks, which will enable only inactive products to be passed to the nearby Woronora River.



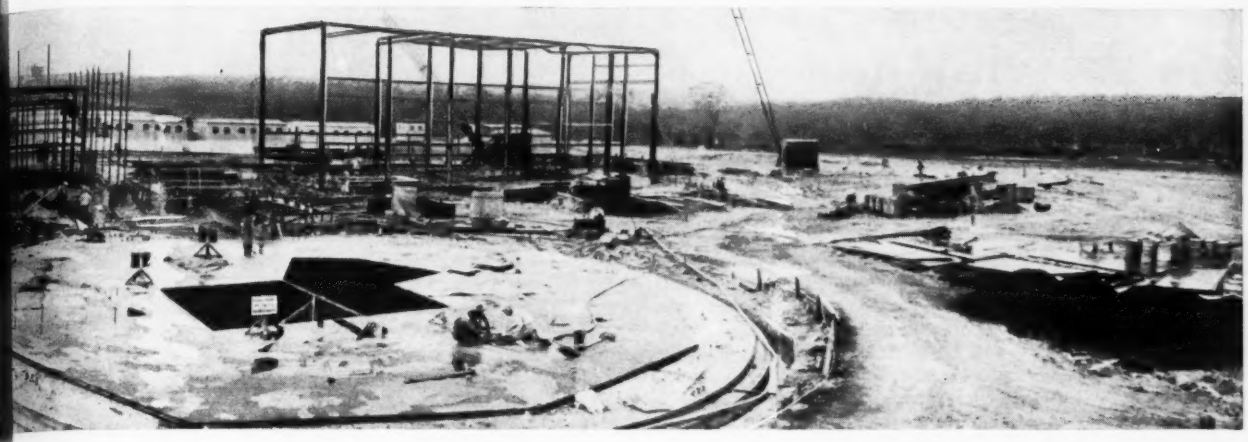
The fuel element storage pit showing the ventilation ducts and reinforcement in position.

Programme d'Etudes de la Commission d'Energie Atomique Australienne

La Commission Australienne de l'Energie Atomique a été guidée par un certain nombre de facteurs lors de l'élaboration de son programme de recherches. Premièrement, en raison de l'entrée tardive de l'Australie dans ce domaine, on a considéré qu'il n'était pas raisonnable d'essayer de développer des réacteurs d'énergie qui seraient déjà dans un état de développement avancé dans les pays d'outremer. Deuxièmement, en raison du manque d'eau dans de nombreuses parties de son continent, l'Australie est intéressée tout spécialement dans les réacteurs susceptibles d'être développés aux températures des turbines à gaz. Troisièmement, tout système de réacteur choisi devrait être à même d'être amené au stage d'expérimentation avec les ressources de l'Australie.

Un examen des systèmes de réacteurs thermiques a montré que l'on avait tout avantage à porter son attention vers un réacteur du type à élément combustible à modérateur imprégné et refroidi par un gaz et vers les réacteurs à refroidissement par métal liquide, dans lesquels le métal liquide est utilisé comme porte-combustible. Dans les deux cas un cycle générateur U 233-Th. a été envisagé. Les nouvelles facilités de recherches à Lucas Heights seront donc orientées en grande partie vers la tenue des matières sous l'irridiation et à hautes températures. Le réacteur de recherches HIFAR actuellement en cours de construction est un réacteur refroidi similaire à DIDO, à flux élevé et à modération par l'eau lourde.

Active area building



Foundations for high-flux reactor HIFAR

The High-flux Australian Reactor (HIFAR) is similar to the British DIDO reactor; we are indebted to the U.K.A.E.A. for making the design information available to us.

As this type of reactor has been fully described elsewhere,[2,3] only the main characteristics are repeated here:—

POWER: 10 MW
FLUX: 10^{14} n/cm^2-sec. maximum
MODERATOR: heavy water
COOLANT: heavy water
REFLECTOR: graphite
FUEL ELEMENTS: Up to 2.5 kg of U 235 in uranium-aluminium alloy.
EXPERIMENTAL FACILITIES: Some 50 vertical and horizontal experimental tubes varying in size up to 12 in. by 8 in.; some in the heavy water reflector with maximum thermal fluxes varying from 5 x 10^{13} to 9 x 10^{13}; some in the graphite with maximum thermal fluxes varying from 0.4 x 10^{13} to 1.5 x 10^{13}. Thermal column 5 ft. x 5 ft.

We shall also construct in Australia a "rabbit" tube to the chemistry laboratories, a neutron spectrometer and a mechanical velocity selector. A contract for the construction of the core of the reactor was let in mid-1955 to Head Wrightson Processes Ltd., in the U.K.; the construction of the necessary buildings, foundations and steelwork commenced in Australia in October, 1955.

In one of the buildings attached to the reactor it is proposed to fit out four manipulator-controlled post-irradiation cells capable of handling pile irradiated samples and loops of up to several tens of thousands of curies. Provision is being made for the cutting up of irradiated samples, machining, chemical treatment and metallurgical examination.

The design of the laboratories is almost complete and provision has been made for buildings to meet the needs of radiochemistry, metallurgy, engineering, effluent control, physics, chemical engineering, library and administration.

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1 Baxter, J. P. *Aust. Journ. of Science*, **17**, 151 (1955).
2 Grout, H. J. and Fenning, F. W. P/402 International Conference on Peaceful Uses of Atomic Energy, Geneva (1955).
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Forschungsprogramm der "Australian Atomic Energy Commission"

Bei der Formulierung ihres Forschungsprogrammes ist die "Australian Atomic Energy Commission" von den folgenden Faktoren geleitet worden: Erstens, weil Australien spät erst das Feld betrat, war man der Ansicht, dass et nicht richtig wäre, Kernkraftwerke neu zu entwickeln, die beraits in einem höheren Entwicklungsstadium in Uebersee vorhanden sind. Zweitens, weil in vielen Teilen des Kontinents Wassermangel herrscht, hat Australien ein besonderes Interesse an Reaktoren, die in der Lage sind die für Gasturbinen erforderlichen Temperaturen zu erzeugen. Drittens, jedes der gawählten Reaktorsysteme sollte mit australischen Hilfsquellen bis zum Versuchsstadium des Reaktors gebracht werden können.

Eine Prüfung der thermischen Reaktorsysteme zeigte, dass der Typ des gasgekühlten Reaktors, der mit bremsstoffimprägnierten Brennstoffelementen arbeitet, besondere Beachtung verdiente, ferner mit flüssigen Metall gekühlte Reaktoren, bei denen das flüssige Metall als Brennstoffträger benutzt wird; in beiden Fällen wird ein Brüterkreislauf mit U 233-Th ins Auge gefasst. Die neuen Forschungsanlagen in Lucas Heights werden daher besonders daraufhin eingerichtet, Werkstoffe unter Bestrahlung und bei hoher Temperatur zu untersuchen. Der Forschungsreaktor HIFAR, der jetzt im Bau ist, ist ein mit schwerem Wasser als Bremsstoff arbeitender und gekühlter "high flux" Reaktor ähnlich wie DIDO.

Programa de Investigación de la Comisión Australiana de Energía Nuclear

Al preparar su programa de investigación la Comisión Australiana de Energía Nucleqr se ha guiado por cierto número de factores. Primeramente, debido a la tardía entrada de Australia en el campo nuclear se consideró innecesario intentar desarrollar reactores de energía que se encuentra ya en estado muy avanzado en ultramar. En segundo lugar, debido a la escasez de agua en muchas partes del continente australiano, Australia siente especial interés en los reactores capaces de desarrollar temperatures de turbina de gas. Y tercero, cualquier sistema de reactor seleccionado debiera poder ser llevado a la etapa experimental de reactores con los medios de que se dispone en Australia misma.

Un examen del sistema reactor térmico demostró que la atención pudiera centrarse con mayores probabilidades de éxito en un tipo de reactor de elemento moderador de combustible impreganado y enfriado a gas, y reactores a metal líquido enfriado en los que el metal líquido se emplea como transportador del combustible: en ambos casos se prevee un ciclo de generación de U 233-Th. Las nuevas facilidades de investigación de que se dispone en Lucas Heights serán encauzadas, por consiguiente, en gran medida al comportamiento de materiales bajo irradiación y a altas temperaturas. El reactor de investigación HIFAR, que ahora se viene construyendo, es un reactor de alta fusión moderado y enfriado por agua pesada similar al DIDO.

The Prevention of Unwanted Criticality

by
A. H. GILLIESON, B.Sc., Ph.D.
Criticality Officer, A.E.R.E., Harwell

The main factors affecting critical mass, and thus nuclear safety, are shape, neutron moderation, concentration of fissile material in solution, neutron reflection, density charge, dilution, and interaction of units containing fissile material. These are considered in the light of their effects on handling, processing, fabrication, transport and storage of fissile material.

A CHAIN reaction can be produced either by fast neutrons moving at speeds near those at which they are produced by the fission of the fissile material, or by slow neutrons moving at so-called "thermal speeds" (about 2,200 metres/second) and slowed down to these speeds by suffering elastic collisions with atoms of other elements.

The probability of fission of an atom of fissile material by slow neutrons is much greater than that by fast neutrons, so that in general there is a greater possibility of achieving criticality in a system where the fission neutrons are slowed down than where they remain substantially fast. Thus a lump of fissile metal quite safe when bare or surrounded by an inefficient moderating material—might not be safe if surrounded by a good moderator such as beryllium, graphite, oil or water. A block diagram Fig. 1 shows the main factors involved in the achievement of criticality. It will be appreciated that if the achievement of criticality is to be avoided the factors represented by the "blocks" to the right and left of the main "circuit" should be as large as possible, so that for every fission neutron of one generation, there shall on the average be less than one fast or thermal neutron available for the next fission generation. This is often loosely termed "criticality control." Necessary in many aspects of nuclear energy work, its importance is increasing daily as larger and larger amounts of fissile material are produced and handled.

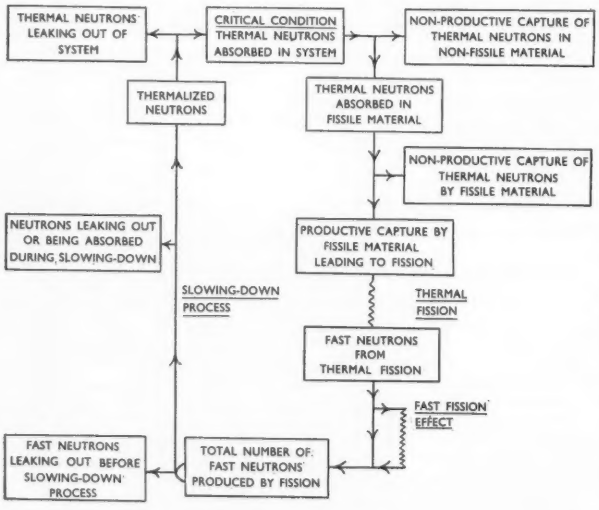
THERMAL NEUTRONS LEAKING OUT OF SYSTEM
CRITICAL CONDITION THERMAL NEUTRONS ABSORBED IN SYSTEM
NON-PRODUCTIVE CAPTURE OF THERMAL NEUTRONS IN NON-FISSILE MATERIAL
THERMALIZED NEUTRONS
THERMAL NEUTRONS ABSORBED IN FISSILE MATERIAL
NON-PRODUCTIVE CAPTURE OF THERMAL NEUTRONS BY FISSILE MATERIAL
NEUTRONS LEAKING OUT OR BEING ABSORBED DURING SLOWING-DOWN
PRODUCTIVE CAPTURE BY FISSILE MATERIAL LEADING TO FISSION
SLOWING-DOWN PROCESS
THERMAL FISSION
FAST NEUTRONS FROM THERMAL FISSION
FAST FISSION EFFECT
FAST NEUTRONS LEAKING OUT BEFORE SLOWING-DOWN PROCESS
TOTAL NUMBER OF FAST NEUTRONS PRODUCED BY FISSION

Fig. 1. Main factors involved in the achievement of criticality.

From the recent Government White Paper outlining the Civil Nuclear Power Programme, it can be inferred that by about 1966, a few tons of plutonium may have to be processed per year in the Atomic Energy Authority facilities, i.e., several kilograms per day. As the critical mass of plutonium in aqueous solution is about half a kilogram, it is obvious that a considerable criticality problem will present itself if the plutonium is to be separated from the depleted natural uranium.

The fast reactor presents a similar problem, for it has been estimated that a fast reactor power station will require the processing of an even greater yearly amount of plutonium.

A Criticality Incident

Where fissile material is involved the most stringent precautions are enforced, and because of the care that has been exercised, there is no actual experience of a criticality accident, in this country.

As the possibility of such an accident cannot entirely be ruled out in spite of all the safeguards taken to prevent it, it is wise to consider the results of a criticality incident in a chemical processing plant, fabrication shop or storage building. Such an accident would not resemble an atom bomb explosion, but would be more like, say, a boiler explosion.

Nearby property within a few feet might be damaged; the immediate surroundings for many square yards might be heavily contaminated with fissile material and fission products. For those personnel standing near the equipment there would be a serious radiation hazard from fast neutrons and gamma radiation. More distant effects would be caused by the spread of airborne contamination, but this process would take time, depending on wind strength, and would allow evacuation of personnel from threatened areas.

The time scale of an accident is very short—of the order of a thousandth of a second. The multiplication factor K is effectively the number of neutrons present at the end of a neutron generation for each neutron present at the beginning of the generation, and thus the number of neutrons will increase by K—1 per generation. Suppose in a particular case, that K=1.0075, and the average neutron lifetime be 0.001 second then in 1 second the number of neutrons will increase about 2,000-fold ($e^{7.5}$).

Criticality Limitations

From the theoretical aspect, the conditions aimed at by the designer are almost the reverse of those arrived at for a reactor. The leakage of neutrons should be as high as possible; that is, it is desirable to use shapes of high surface area to volume ratio, and/or to absorb as many neutrons as possible in materials other than fissile. Reflection of

neutrons back into the fissile material should be avoided, and the density of the system and the concentration of fissile material should be as low as possible.

The main factors, therefore, which affect critical mass and thus nuclear safety, are detailed below:

Shape—The sphere with its low surface-area to volume ratio is the worst shape, when one wants to avoid criticality but the cube and right cylinder with equal height and diameter are almost equally unfavourable.

Only when one dimension differs from the others by about a factor of 3, does the increase of critical mass, compared with that of a sphere, become significant.

With further change in the one dimension relative to the other two, the critical mass increases more and more rapidly, until a limit to this dimension is reached beyond which the system cannot be made critical. The so-called "infinite slab" and "infinite cylinder" have limiting dimensions of thickness and diameter only.

Neutron Moderation—As, in general, the capture cross-sections leading to fission are very much greater for thermal neutrons than for fast neutrons, the critical mass of a sphere of fissile material mixed with a moderator, such as water, is only a small fraction of the critical mass of a sphere of the pure fissile material (as metal). Intermediate values are obtained for lattices of small pieces of fissile material flooded with water.

Other light materials; for example, D (as D_2O), Be (as metal or BeO) and C (as graphite) can also act as moderators but, in practice, hydrogen (as water, oil, organic solvent, human tissue) is the only moderator of importance—usually in solutions, or in accidental flooding. Thus critical masses for a given fissile material range from the two extremes of that for oil solution to that for pure "dry" solid.

Concentration of Fissile Material in Solution—In aqueous solution, there is an intermediate concentration at which the critical mass is a minimum (Fig. 2). This property of fissile material solutions, which is fairly general for thermal reactors, is due to the competing effects of fast neutron non-leakage probability and of K, the multiplication factor. At low ratios of, say H/U 235, the non-leakage probability is small, although owing to the high U 235 concentration, K is large. As H/U increases, K decreases slowly, but the non-leakage probability increases rapidly, and therefore the critical volume increases relatively slowly. As the critical mass is roughly proportional to the critical volume divided by the H/U ratio, if the volume increases less rapidly than the ratio, the critical mass will decrease to a minimum. From this point, the non-leakage probability increases only slowly because of the decreased proportion of fissile material, while K steadily decreases owing to increasing absorption by the moderator. The critical mass increases rapidly becoming infinite when K=1.

$$K = 1 = \eta f = \eta \frac{\Sigma_U}{\Sigma_U + \Sigma_H} = \eta \frac{z}{z+1}$$

$$z = \frac{\Sigma_U}{\Sigma_H} = \frac{\sigma_U}{\sigma_H} \cdot \frac{N_U}{N_H}$$

$$\therefore \frac{N_H}{N_U} = \frac{H}{U} = \frac{\sigma}{\sigma_N}(\eta\text{-}1) = \frac{698}{0.32}(2.1\text{-}1) \simeq 2400 \text{ for } U_{235}$$

Thus below a certain limiting concentration, solutions cannot become critical, regardless of shape, volume, etc., provided that the fissile material remains in solution. At high concentrations of fissile material, the critical mass approaches that of the dry salt, which may be greater than that of the pure fissile material (compact metals).

Neutron Reflection—Almost any non-fissionable material surrounding a core containing fissile material acts as a neutron reflector and, for instance, the critical mass of a sphere surrounded by several inches of water, steel, or graphite (or any of a number of common materials) is roughly half that of a bare sphere.

Density Change—A decrease in density of a system containing fissile material, without change in composition, increases the critical mass significantly. This decrease means that there are a smaller number of atoms per unit volume, and thus, *inter alia*, the probability of neutron capture leading to fission is reduced. Diffusion, slowing down, and migration length are also inversely proportional to density.

Dilution—Where the fissile material is metal, moderate dilution by almost any non-fissile material except hydrogen, increases the critical mass, and this dilution effect is almost entirely due to the decrease in density. If the number of diluent atoms does not exceed the number of fissile atoms, the effect of the diluent as moderator or poison will generally be small. As the capture cross-section of most elements is greater for thermal than for fast or intermediate neutrons, the poisoning effect of a diluent, due to its neutron absorbing properties, may be much greater in solution than in the "dry" metal, because of the greater degree of thermalizing of neutrons in solutions.

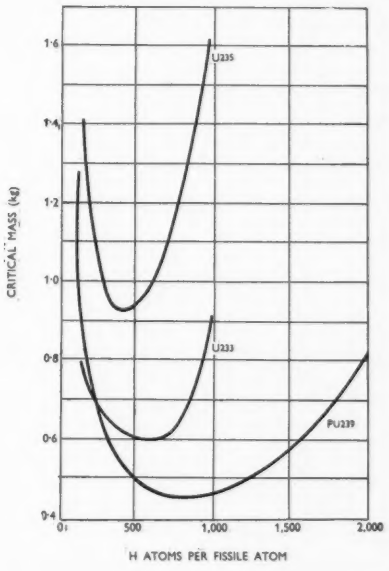

Fig. 2. Comparison of results for concentrations of U233, U235 and Pu239 in water, for spherical systems.

Interaction of Units containing Fissile Material—Units containing fissile material, themselves sub-critical, may, in proximity to one another, become critical. Well-known examples of such units, are the natural uranium rods in a thermal graphite pile. These interactions have been studied in air and water, and the most useful generalization resulting is that an array of units each of which is, by itself, sub-critical in water, will be safe when flooded, provided no separation between units is less than about six inches.

Such studies of interaction of units are of great value for storage problems and for plant layout; for instance, where units of fissionable material are stored in close-fitting holes in concrete blocks, the number of units in a critical array is roughly proportional to the volume allotted to each unit.

Criticality in Practice

Criticality problems arise particularly in chemical processing, and general and typical problems in this field will be considered.

Chemical Processing—Before a chemical plant becomes an operating reality, it must pass through four stages: process choice; plant design; building of plant; and operation of plant.

At each of these stages, criticality assessments and decisions can affect the final safety of the plant, and although the majority of these will and should arise in the first two stages, nevertheless, decisions at all stages interact on one another and the four stages cannot be considered separately and in isolation from one another.

It will be obvious that certain types of process may be subject to less criticality limitation than others. In general, "dry-way" will be superior to "wet-way" processes, because of the greater degree of moderator and reflector effects to be expected in the latter. Although a "dry-way" process can show advantages of up to a factor of five over "wet-way" processes, the effect of crucible materials such as graphite must not be forgotten.

In both types of process, the presence of neutron absorbers can reduce criticality limitations if their presence in the mixture or solution can, under all eventualities, be guaranteed.

Continuous processes will have advantages over batch processes, if, thereby, the hold-up volume is smaller and provided that there are no slow steps in the reaction. Build-up of material has to be guarded against, particularly in continuous processes. Continuous methods for dissolving or for solvent extraction of fissile material are examples of processes where such considerations arise.

Single-stage processes are favoured in comparison with multi-stage, for clearly the fewer the number of steps in a process, the easier it is to control.

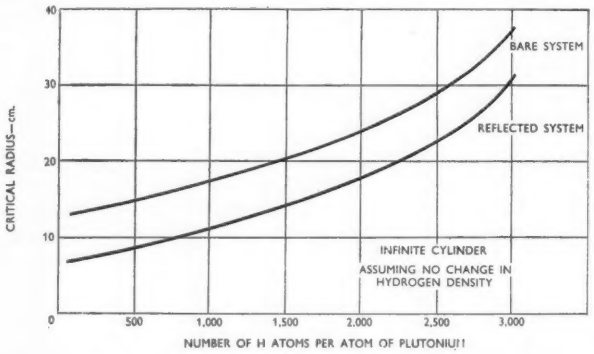

Fig. 3. Critical radius graph for a vessel of the "infinite cylinder" type for a plutonium and water solution.

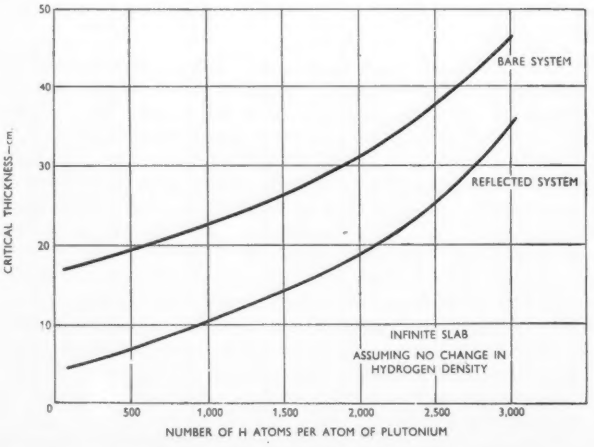

Fig. 4. Critical thickness for "infinite slab" type of vessel, for a plutonium and water solution.

Assuming initially that each assembly which might become critical, is perfectly isolated from any other possible source of neutrons, certain guiding principles can be laid down. If the fissile material is in solution; two approaches are possible:

(a) The concentration is maintained below the limiting concentration at which the solution can just become critical at infinite volume; or

(b) vessels are employed of the "infinite cylinder" or "infinite slab" type, by using columns, cylindrical vessels, and piping, whose diameters are less than that of the infinite cylinder, or by employing flat catch-basins or trays of the proper area, so that in the event of a leak the thickness of solution cannot exceed that of an infinite slab. Such vessels are commonly called "eversafe" but they are only safe under conditions for which they are designed.

(b) is preferable to (a) because once made safe, shapes cannot easily be changed, whilst fixing concentration limits involves operational and analytical control, to ensure that the concentration does not exceed the safe limit, for example, by accidental evaporation; or that a change in physical state does not occur in the solution, for example, alteration of pH causing precipitation of fissile material and a consequent effective decrease of the H/fissile material ratio.

Care has to be taken even with "eversafe" vessels that the amount or nature of moderator or reflector does not change. Replacement of an aqueous by an organic solution of fissile material, might make a design no longer safe.

When a system can be guaranteed as "unreflected," then criticality limitations can be relaxed, but provision must still be made for possible accident—flooding of a steam jacket by water would convert the system from virtually unreflected to very complete reflection.

Flooding in general is a hazard with unreflected systems and should always be considered.

Internal absorbers have often been proposed as a means of easing criticality limitations, but little use has been made of such "neutron poisons" to date because their inclusion in the particular process would have been undesirable for normal chemical reasons, apart from the necessity of ensuring that they were uniformly distributed (in the solid case) or could not accidentally be separated from the fissile material (in the solution case).

External fixed solid absorbers are of greater potential value but their use is not widespread and experimental and theoretical work is required in this field.

The main use of such absorbers has been to isolate or shield one plant unit from another. Because of the greater absorption efficiencies for thermal neutrons, external absorbers are often used in conjunction with moderators, and often consist of sandwiches of cadmium sheeting and a hydrogeneous material such as paraffin wax or Perspex.

Apart from interaction between neighbouring vessels, plant lay-out as a whole must be considered. Piping runs between vessels must be designed for safety, and the usual method of tying bunches of pipes together and keeping them rigidly parallel, can constitute an unsafe design. Piping carrying fissile material solutions or even potential carriers of such solutions —in event of plant mal-operation or accident—must be arranged in a spacing dictated by criticality considerations.

Where a criticality hazard might occur, not only is it necessary to consider plant layout as a whole, but it is advisable to study the whole process and plant from the criticality angle at an early flow-sheet stage before fixing the building size.

A plant layout cramped because the building size was fixed too soon can multiply criticality problems and necessitate the introduction of costly shielding to prevent interaction between units placed too close together.

Although operational flexibility is a desirable feature in a plant, too much can produce severe criticality limitations,

and a nice judgment must be exercised between such flexibility and the almost inevitable demand for increased throughput on sound economic grounds.

Due allowance must be made at the design stage for these two often competing factors, otherwise economic advantages must be sacrificed or costly modifications undertaken.

In other than "eversafe" portions of any plant, any change in operating conditions must be preceded by an assessment of the criticality implications.

If a plant consists of an "eversafe" portion and a portion where operational control has to be carried out, then care must be taken that sludges or precipitates—safe in the "eversafe" vessels—are not carried forward to other vessels where they are not safe.

In such a mixed plant reliance for safe operation has to be placed on fissile material accountancy, involving considerable analytical effort and resulting in possible frequent and costly cleaning out of plant.

Fissile material accountancy is always necessary in such plants, but should be kept to a minimum for it is expensive, often slow, and is not automatic in operation.

Sampling points must be very carefully chosen so that the sample is truly representative, and adequate metering, although costly, has already proved of value.

Neutron monitoring is useful for detecting build-up of fissile material in vessels but in a monitoring rather than a control sense.

Storage and Transport—In both these operations, safety considerations similar to those described for chemical processing arise, and the same factors serve as a guide to safe design, "eversafe" shapes, "eversafe" concentrations, external absorbers plus moderators to prevent interaction of units, precautions against the effects of flooding and of fire, and operational control so that no more than a safe amount can be transported in a vehicle, or removed from storage simultaneously.

Fabrication—The machining of fissile materials has its own criticality problems. No more than a safe amount of, say, metal must be allowed in a machine shop at one and the same time, and, for example, a system of tallies operated by the fissile materials storeman could be arranged to guard against the inadvertent accumulation of more than safe amounts in the same shop.

The disposal of casting, milling and turning wastes must be rigorously controlled, not only because of their economic value but also because their uncontrolled accumulation can be a serious hazard. In turning operations, for example, fissile metal particles can become mixed with oil or cutting oils, and the criticality limitations on such a sludge are severe.

Research Experimental Work—Where criticality may arise, the design and operation of experiments involving fissile material require very careful consideration. Fortunately the vast bulk of experimental work on fissile materials can be carried out with amounts well below the critical, and every endeavour is made to ensure that no more material is involved than is adequate for the particular investigation.

Conclusions—Unwanted criticality can be avoided by making use of favourable geometry, limitation of mass of fissile material, limitation of working volume, and the use of absorbers. Process choice and selection of suitable plant, coupled with careful over-all plant design, can minimize criticality restrictions.

Although cases involving simple geometries can be calculated with some accuracy, the often complex geometries necessary in plants may not permit of accurate mathematical calculation and recourse must be made to experiment. Such criticality experiments must be carefully planned, so that their results can be interpreted into plant design. Oversimplification of the model used for calculation or experiment,

La Prévention de la Criticalité Indésirable

Les précautions nécessaires pour éviter la criticalité indésirable dans la manipulation, le traitement chimique, la fabrication, le transport et le magasinage des matières fissiles, sont étudiées dans un traité non-mathématique donnant les grandes lignes des principes théoriques et des considérations pratiques qu'entrainent le tracé et le fonctionnement des installations.

Le concept de la criticalité est défini et expliqué brièvement. Il est suivi par une définition du contrôle de la criticalité indésirable et d'une indication de son importance toujours croissante.

Après avoir fait la description de la nature d'un accident de criticalitéun fait ayant peu de chance de se présenter en vue des précautions rigoureuses que l'on prend—on passe en revue les limitations imposées par les considérations de criticalité, et l'on cite un certain nombre de généralizations utiles. Les principaux facteurs affectant la masse critique sont: la forme, la modération des neutrons, la concentration de matières fissiles en solution, la réflection des neutrons, le changement de densité, la dilution et l'interaction des unités contenant de la matière fissile.

L'effet de ces limitations sur les procédés chimiques, sur le tracé et le fonctionnement de l'installation y est envisagé et l'application de ces limitations au transport, à l'emmagasinage, à la fabrication et à l'expérimentation ayant trait à la matière fissile y est décrite dans les grandes lignes.

Verhütung des kritischen Zustandes

Die Vorsichtsmassnahmen, die man anwenden muss, um zu verhüten, dass der kritische Zustand beim Arbeiten mit Atomzerfall unterliegenden Stoffen erreicht wird, sowohl bei ihrer chemischen Behandlung als bei Herstellung, Transport und Lagerung, werden diskutiert, ohne auf mathematische Berechnungen einzugehen, wobei die theoretischen Grundsätze und die praktischen Erwägungen, die dem Entwurf und dem Betrieb der Anlagen zu Grunde liegen, aufgezeigt werden.

Der Begriff des kritischen Zustandes wird definiert und kurz erklärt, es folgt eine Definition der Kontrolle unerwünschten Ereichens des kritschen Zustandes und ein Hinweis auf ihre wachsende Bedeutung. Nach einer Beschreibung der Natur eines versehentlich eintretenden kritischen Zustandes—ein sehr unwahrscheinlicher Fall im Hinblick auf die scharf überwachten Vorsichtsmassnahmen —wird eine Uebersicht über die Einschränkungen, die Erwägungen des kritischen Zustandes auferlegen, gegeben, und es wird eine Reihe brauchbarer Verallgemeinerungen gebracht. Die Hauptfaktoren, die den kritischen Zustand einer Masse beeinflussen, sind: Form; Abbremsung der Neutronen; Konzentration einer Lösung von dem Atomzerfall unterliegenden Stoffen; Neutronenreflektion; Wechsel in Dichte; Auflösung; schliesslich Wirkung von Einheiten die dem Atomzerfall unterliegende Stoffe enthalten, aufeinander.

Das Resultat dieser Beschränkungen in Bezug auf chemische Prozesse, auf den Entwurf von Anlagen und auf den Betrieb wird erläutert, und die Anwendung bei Transport, Lagerung, Fabrikation und bei Forschungsarbeiten dargelegt.

Prevención de Criticalidad no Deseada

En un trabajo de índole no matemática se discuten las precauciones necesarias para evitar la criticalidad no deseada en el manejo, preparación química, fabricación, transporte y almacenaje de materiales fisionables, y en el cual se perfilan también los principios teóricos y las consideraciones prácticas que se presentan en el planteo y operación de una fábrica. El concepto de criticalidad se define y explica con brevedad y a esto sigue una definición para el control de la criticalidad no deseada, con una indicación de su importancia creciente.

Después de describir la naturaleza de un accidente de criticalidad, ocurrencia no probable en vista de las estrictas precauciones adoptadas, se estudian las limitaciones que las consideraciones de criticalidad imponen y, a la par, se citan cierto número de generalidades útiles. Los factores principales que afectan la masa crítica son: forma; moderación de neutrones; concentración de material fisionable en la solución; reflejos de neutrones; cambio de densidad; disolución, y, la interacción de unidades que contienen material fisionable.

El efecto de estas limitaciones en los procedimientos químicos y en el diseño y funcionamiento de la planta, también son estudiados, así como su aplicación al transporte, almacenaje, fabricación y trabajos experimentales con materiales fisionables.

can give rise to misleading results and is to be avoided at all costs.

In general, nuclear safety or the avoidance of criticality hazard requires continuing development of calculational methods, practical experimentation and of design for criticality.

In the United Kingdom, prevention of unwanted criticality is covered by bodies of experts charged with the duty of ensuring criticality safety in operations involving fissile material. From design to production stages they assess the precautions necessary and are assisted in this by teams carrying out calculations and experiments. This safety organization has under continual and continuing review all operations involving fissile material and inspects records, plant, transport and storage at frequent intervals.

Acknowledgments

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Tandem Accelerator for Canada

A 10-MeV particle accelerator of unusual design is to be installed at Chalk River for Atomic Energy of Canada Ltd., early in 1958. Known as the tandem accelerator, the machine will enable continuous detailed studies to be made of the nuclear energy levels of heavy elements: so far, the equipment at Chalk River has allowed the study of only certain of the light atomic nuclei.

The machine is being developed and constructed by High Voltage Engineering Corporation, Cambridge, Massachusetts, and comprises two specially designed Van de Graaff generators placed end to end in a horizontal position to give an over-all length of 34 ft. and a diameter of 8 ft. Weighing 35 tons, the accelerator will be mounted on rails and housed in an L-shaped building 150 ft. long and 60 ft. wide. This building, which is now under construction, is located against a hillside so that the ground will act as shielding against the high energy radiation on one side, whilst thick concrete walls will shield the other sides. Controls and services will be housed in a separate building.

As yet, little information has been given on the machine beyond an outline of some of its more interesting features. The beam of high-speed particles will be focused and deflected in a series of powerful electromagnets into an experimental area 25 ft. from the accelerator. A switching magnet is incorporated which makes it possible to shift the beam to any one of five directions within the experimental area. There is also a unique method of charge exchange whereby the electric charge of a particle is changed during acceleration permitting a 5-million volt potential to give a 10 MeV particle. This system of acceleration was originally invented by Dr. W. H. Bennett and developed by Dr. Luis Alvarez.

So far as its application to the tandem-style Van de Graaff accelerator was concerned, it was essential to have a source of negatively-charged hydrogen ions. The development of such a source was carried out by Professor R. G. Herb and his associates at the University of Wisconsin.

Positive hydrogen ions are, therefore, made negative before being accelerated into the Van de Graaff: at the half-way stage of acceleration, the negative ions are stripped of their excess electrons so that they can accelerate "downhill" using the same voltage.

Atomic Energy of Canada Ltd. hopes that the use of this machine will result in important advances in fundamental research on heavy nuclei. At present there is a 3-MeV Van de Graaff at Chalk River and two smaller cascade generators of 100 keV and 355 keV.

Course for Scottish Industrialists

The Industrial Group of the A.E.A. and the Central Electricity Authority co-operated in a venture to give senior industrial executives in Scotland a review of the developments as well as the problems in nuclear engineering. The conference took the form of discussions held at the Royal Technical College, Glasgow. The sessions were arranged over the three days, July 2-4, with ample time for questions. Talks were given by C. E. Iliffe on the principles of nuclear energy and types of nuclear power stations and by D. L. Linning on heat transfer and reactors. Metallurgy was dealt with by A. B. McIntosh and operating characteristics by J. Bowen. The C.E.A. nuclear power programme and system planning were discussed by R. H. Burdett, whilst J. C. Duckworth spoke of nuclear power developments overseas.

The most encouraging feature of the conference was the excellent response by Scottish industry. Companies represented included all the Scottish electrical generating authorities, electrical contractors, plant manufacturers, ship builders, civil engineers, steel makers and the Scottish Council.

National Certificate in Applied Physics

Part-time courses in applied physics are being run at Leeds and Rotherham Colleges of Technology in conjunction with the Institute of Physics and the Ministry of Education.

The Ordinary National Certificate course is open to boys and girls with a good science record at a secondary school. Exemption from parts of the course may be granted to applicants with appropriate G.C.E. qualifications and to older students who already hold a National Certificate in another technology or a partial qualification gained at a college outside the area. Normally, however, the course requires attendance for two half-days and one to two evenings a week for three years.

There is also a Higher National Certificate course, requiring two years' part-time attendance, open to students possessing an Ordinary National Certificate in applied physics, or having reached an equivalent standard.

Full information may be obtained from the secretary, Yorkshire Council for Further Education, Upper Basinghall Street, Leeds.

Second Annual Report of the U.K.A.E.A.

THE second annual report of the work of the U.K.A.E.A., covering the period from April 1, 1955, to March 31, 1956, was submitted by the Lord President of the Council to Parliament on July 25. The report covers the activities of the A.E.A. with a brief discussion on future trends and comments on such aspects as co-operation with industry and other nations. The considerable increase of activity in the development of atomic energy for peaceful purposes is emphasized, but the importance of the weapon programme is not omitted. The development of nuclear weapons, particularly the hydrogen bomb, receives a very high measure of priority.

Calder Hall

Developments during the year on the Calder Hall project have made it possible to establish the official opening by Her Majesty the Queen as October 17; at that time one of the two reactors only will be in full operation. Ultimately power supplied to the grid is expected to be 65 MW derived from four 23 MW turbo-alternator sets. Special mention is made of the mechanical problems associated with the lifting of the eight heat exchangers, each weighing 200 tons, into position.

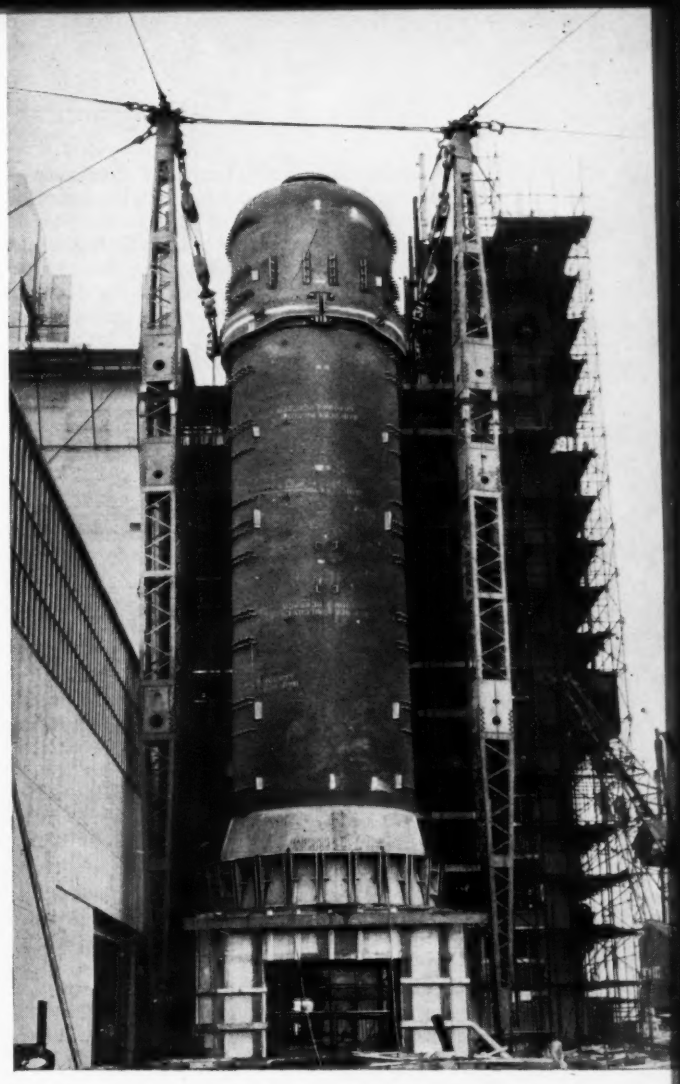
In order not to interfere with the civil programme for nuclear power and the Authority's pioneer work on new types of reactors it has been decided to build three additional units similar to Calder Hall A. These will be Calder Hall B alongside the first station and a similar pair (with four reactors) at Chapel Cross, near Annan, Dumfriesshire. The report in its comments on the programme for nuclear power does not go further than the White Paper of February, 1955, in which the 10-year programme plans a generated capacity of 1½-2 million kW, this figure being increased to 10-15 million kW by 1975.

U.K.A.E.A. and Industry

An outline is given of the steps taken to bring industry more fully into the programme following the publication of the White Paper. Senior members from the four consortia (A.E.I.-John Thompson Nuclear Energy Co. Ltd., the General Electric - Simon Carves - Motherwell Bridge group, the English Electric-Babcock and Wilcox-Taylor Woodrow group and the Nuclear Power Plant Co. Ltd.) attended courses at the Harwell reactor school. Further courses were organized at the Authority's industrial group establishments and examination of the Calder Hall project was encouraged. Selected members from the four teams then continued with more specialized courses. From these nuclei of trained people the individual groups have set up their own design and research laboratories.

A nuclear power collaboration committee was also set up including representatives from the four groups, from the Atomic Energy Authority and from the Central Electricity Authority. More recently, representatives of the South of Scotland Electricity Board have joined the committee.

This system has allowed industry steadily to increase its participation in the nuclear power programme and the report states that the Authority have regarded the dissemination of information to industry as one of its principal responsibilities.



Erection of one of the steam-raising towers at Calder Hall. The unit has just been placed in position on its foundations.

The reactor school has continued to function with a steadily increasing intake and curriculum so that by the beginning of this year a total of 199 full-time and 100 part-time students had passed through.

Access to Information

Unclassified information is now available to all interested concerns and a monthly list of unclassified documents is issued by the Authority, copies of which can be obtained free of charge from A.E.R.E., Harwell. Copies of the documents are supplied to the following libraries: The Science Museum Library, London; Sheffield Central Library; The Central Library, Birmingham; The Mitchell Library, Glasgow; The Central Library, Liverpool; The Central Library, Manchester; The Central Library, Newcastle, and some are available through H.M.S.O.

The term "classified" has now a wider meaning than in the immediate post-war days as companies working in the atomic energy field now have access to information relevant to power reactor projects. Access agreements with the A.E.A. are drawn up in which payment must be made to the Authority for information and patents developed at considerable expense to the taxpayer, and individual companies are prevented from obtaining exclusive rights in any particular basic reactor system. In general, access is made in the form of reports or visits for consultation but over 100 engineers and scientists from industry have been attached to the A.E.A.'s establishments.

The report exemplifies the growing interest in atomic energy developments by companies not associated with the four consortia by pointing out the formation of Vickers Nuclear Engineering Ltd., composed of Vickers Ltd., Rolls-Royce Ltd. and Foster-Wheeler Ltd., who are considering the application of nuclear energy to marine propulsion. The Hawker-Siddeley Nuclear Power Co. Ltd. are beginning initial studies on liquid metal fuelled reactor systems and the British Ship Building Research Association has a team at Harwell studying feasibility units for marine propulsion. This list is of course by no means complete as a number of companies, such as Richardsons-Westgarth Atomic Ltd. and Ruston-Hornsby, are interested in whole or part reactor power units.

Export of Reactors

The report states that the export of nuclear reactors will be the responsibility of industry and not of the Authority although the supply of fuel will remain in the control of the A.E.A. Supplies of natural uranium are sufficient to meet all expected demands and enriched fuel, although in short supply, is being allocated to industry—the first of this will go to A.E.I.-John Thompson Nuclear Energy Co. Ltd., for the construction of MERLIN. The report does not envisage any considerable market for exports, however, and although it concedes that there is some demand from overseas countries for research reactors it anticipates that orders for power reactors will await the completion of the first C.E.A. installations.

Isotopes

Sales of radioactive isotopes have continued to increase to a figure of nearly £½ million over the twelve months of which more than half is for export. The isotope school has continued to be in great demand and 167 students have attended the ordinary course at Harwell and 104 special courses.

To increase the research facilities on irradiation effects the technological radiation group has been set up which will have the use of spent fuel elements from the reactors DIDO and PLUTO, giving a radiation source of approximately 1 million curies. Cobalt-60 has an ever increasing use in cancer therapy units and the production of caesium-137 will replace many 200-kV X-ray machines.

Research

A vast programme of research lies ahead to extend the efficiency of the Calder Hall type station and to develop new reactor systems. Of the various types of reactor system possible in the stage 2 programme, work is to be concentrated on the sodium-graphite and the pressurized water reactors. A number of experimental loops to study the corrosion effects in pressurized water reactors have been set up in NRX in Canada and BEPO at Harwell and further loops will be installed in DIDO when it comes into operation. Fuel specimens under examination have included highly alloyed uranium and uranium oxide and these have been investigated for damage by irradiation. Zirconium is of considerable significance in this type of reactor although aluminium alloys have been considered for shielding the fuel. Diphenyl and terphenyl are also considered as possible alternatives to water and studies on this system are going ahead rapidly.

It is possible, however, that the first Stage 2 reactor to be studied on an experimental scale will be a sodium-graphite reactor, once the problems of either canning or sealing the graphite have been solved. Design work on a prototype will probably start at the end of this year.

For Stage 3 of the programme four reactor systems are being investigated, the first of which is a fast reactor. The prototype model at Dounreay is well advanced in construction and is due for operation in late 1959, the experimental data being supplied by ZEPHYR, which began operation at the beginning of 1955. The aqueous homogeneous reactor which should realize a system with very low fuel costs involves many problems in metallurgy. However, studies on the effects of irradiation on uranium solutions are well advanced and an assessment has been made of a power reactor generating about 100 MW to detail the design data required from a reactor experiment. The other two systems under investigation are the liquid metal fuel reactor and the high temperature gas-cooled reactor aimed at producing an outlet temperature suitable for gas-turbine operation.

It is anticipated that one or two of these four reactor systems will be selected in 1957-1958 as a basis for a low-powered reactor design to test the general technology of the system and its possible application to the development of nuclear power stations with a 10-MW output.

Thermo-nuclear Reactions

Little information is given on the experimental work undertaken in this field except the bare statement that a programme of research into the possibilities of obtaining economic power has been in hand. The report quotes the figure of 100 million degrees as being the temperature necessary, although other figures quoted have put it as low as 14 million degrees.

Uranium Supplies

There has been a considerable increase over the past twelve months in the production of uranium throughout the world and the production and sale of uranium are now reduced to normal commercial transactions. It is probable that the forecast by the U.S.A.E.C. giving an expected price for high-grade concentrate of 71 shillings per lb. will soon be realized. At the beginning of the year the United Kingdom continued to depend on contracts placed by the Combined Developments Agency on behalf both of the Authority and the U.S.A.E.C., but recently contracts have been placed directly with the suppliers. A considerable contract has been awarded to the Mary Kathleen mine in Queensland, Australia, for example, but the Authority is also encouraging prospecting in other areas such as the Central African Confederation.

Health

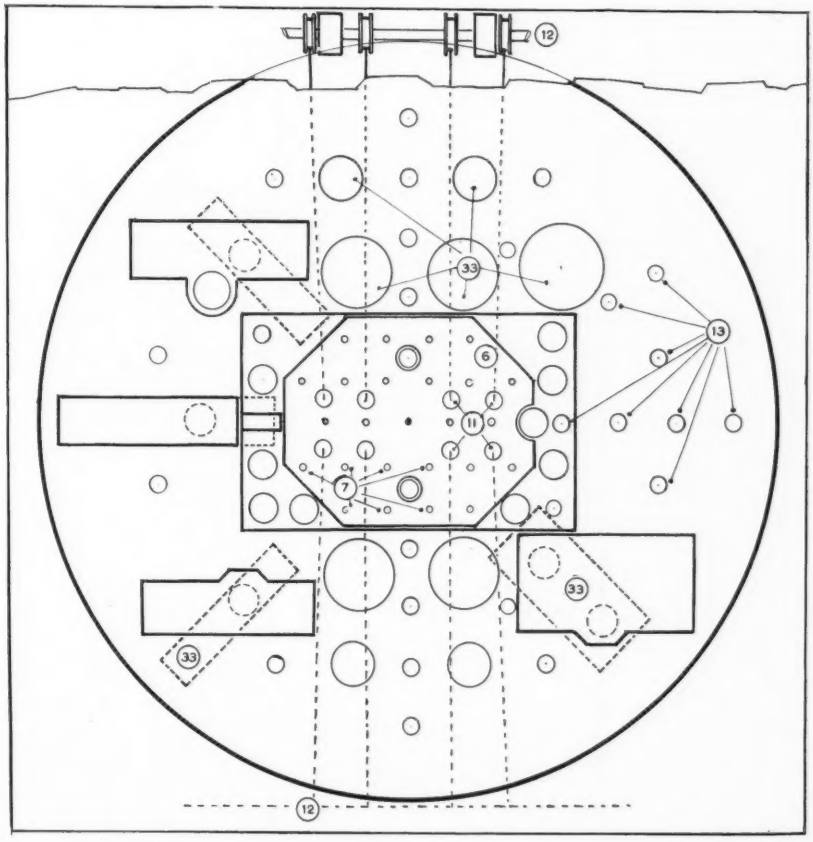
To control the setting up of reactor assemblies and power stations the Authority has set up a panel of its own specialists, together with representatives of the electricity authorities, to determine suitable sites. The sites for the first two stations have been selected at Berkeley in Gloucestershire, and Bradwell-on-Sea in Essex and recently the go-ahead was given to the C.E.A. for permission to build at these two places.

Figures in the Authority for illness and absence compare favourably with other equivalent industries. In the period under review there was no case of occupational toxicity illness or death, and lost time frequency rates for the year ending September, 1955, were 1.01 per 100,000 man hours for the Industrial Group, 0.42 for the Weapons Group and 0.95 for the Research Group.

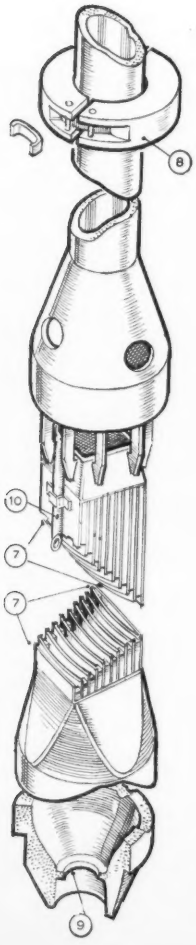
International Co-operation

The United Kingdom was one of the 12 countries which drafted the plan for an international agency. At the same time a number of bilateral agreements have been made with individual countries and the Government has been considering a number of proposals for closer European co-operation through O.E.E.C. The policy towards Euratom remains similar to that adopted towards the steel pool. The following countries having agreements with Britain or other forms of collaboration or have taken part in detailed technical discussions: Australia, Canada, India, Pakistan, South Africa, the United States, Argentine, Austria, Belgium, Brazil, Denmark, France, Iran, Iraq, Israel, Italy, Japan, Jugoslavia, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey and Western Germany.

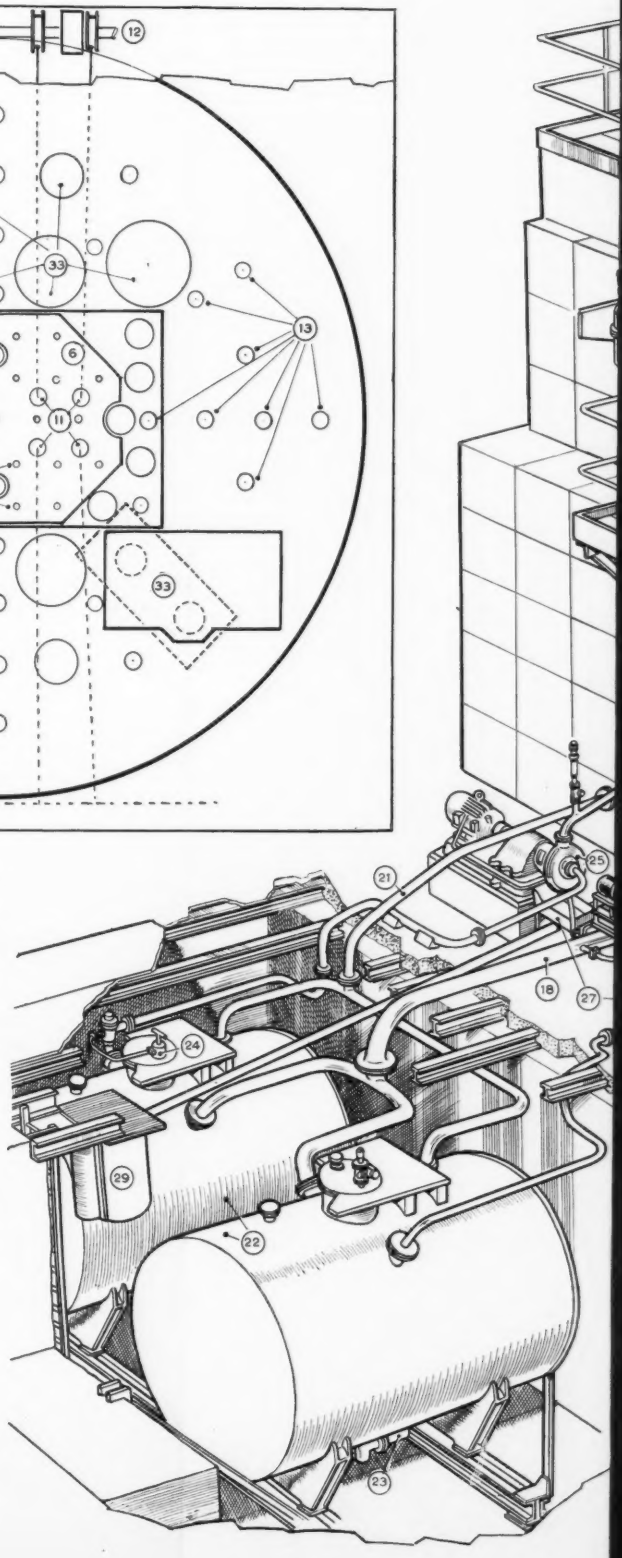
The World's Reactors
No. 4 — DIMPLE



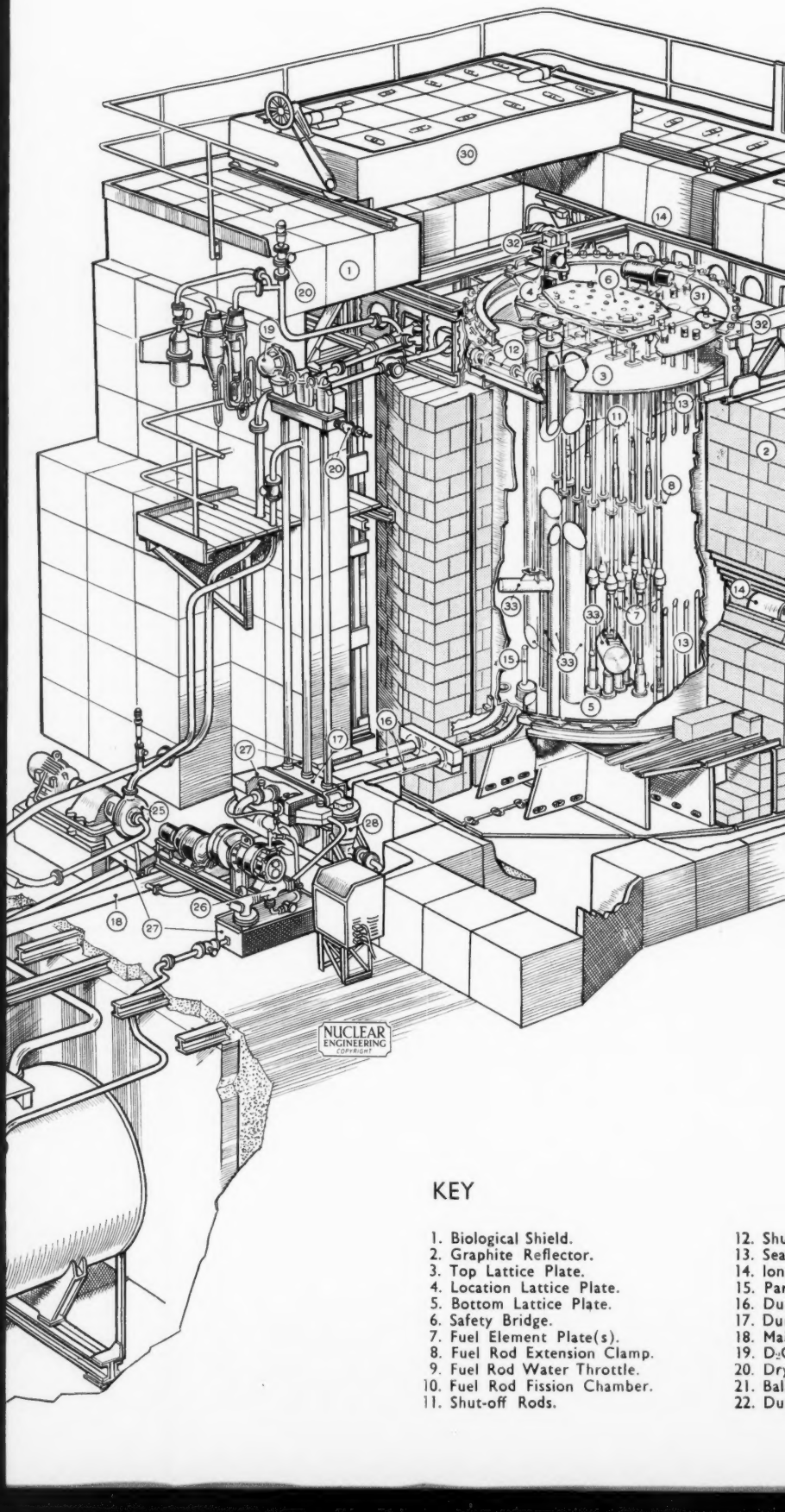
Above—Plan of top face of the reactor with biological shield removed. The safety bridge secured by padlock and interlock catch prevents modification of the lattice except during shut-down. Fuel element assemblies are seen terminating in set screws. Dispositions of simulating voids and search channels are indicated.



Left—Fuel element assembly. Individual plates are made from vacuum cast ingots of U-Al alloy which are rolled to thickness and then clad in Al and rolled to size and shape. Individual plates are soldered together with Al spacers to form box units. Cooling is by natural circulation.

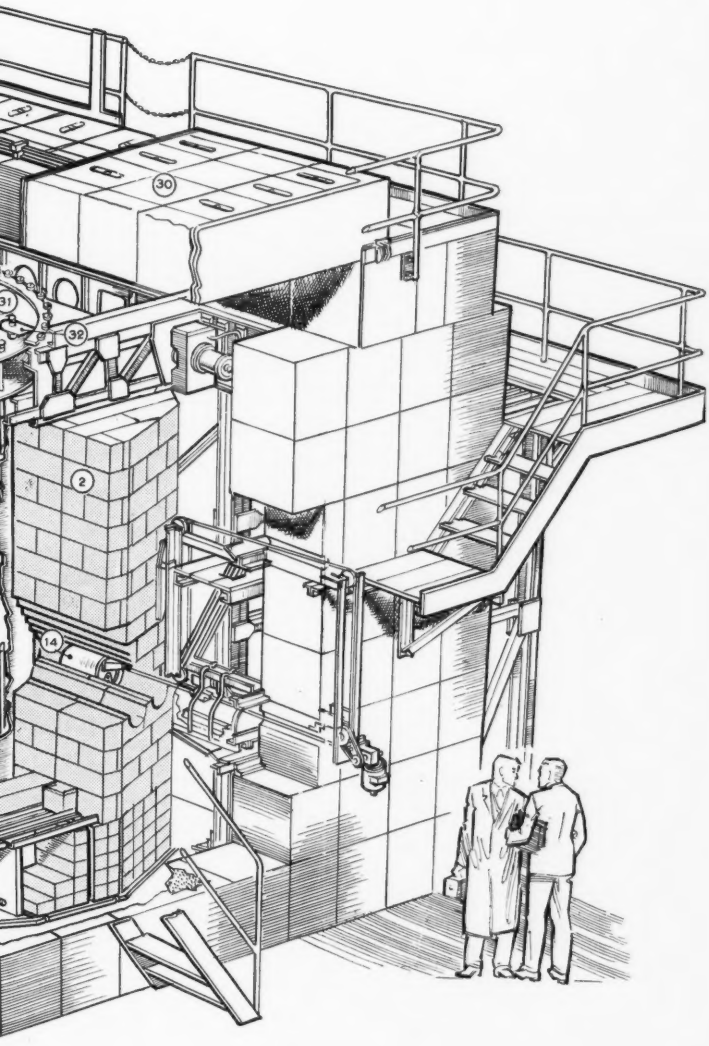


Right—Cut-away view of the reactor showing DIDO core under test. Lattice is surrounded by voids and absorbers to simulate experimental holes and is provided with additional negative reactivity in the control system. D_2O circuit is shown with freezer-drier unit for heavy water reclamation prior to a lattice change.



KEY

1. Biological Shield.
2. Graphite Reflector.
3. Top Lattice Plate.
4. Location Lattice Plate.
5. Bottom Lattice Plate.
6. Safety Bridge.
7. Fuel Element Plate(s).
8. Fuel Rod Extension Clamp.
9. Fuel Rod Water Throttle.
10. Fuel Rod Fission Chamber.
11. Shut-off Rods.
12. Shu
13. Sea
14. Ion
15. Par
16. Du
17. Du
18. Ma
19. D₂O
20. Dry
21. Bal
22. Du



12. Shut-off Rods Wind-gear.
13. Search Tubes.
14. Ion Chamber.
15. Partial Dump Stand Pipe.
16. Dump Lines.
17. Dump Valves.
18. Main Dump Line.
19. D_2O Level Transmitter.
20. Drying Connection.
21. Balance Line.
22. Dump Tanks.
23. Dump Tank Balance Line.
24. Primary Pump.
25. Transfer Pump.
26. Control Pump.
27. Leak Shrouds.
28. Control Dump Valve.
29. D_2O Leak Tank.
30. Travelling Top Shield.
31. Removable Tank Top.
32. Herriott Probe.
33. Voids.

The World's Reactors No. 4

DIMPLE — DEUTERIUM MODERATED PILE, LOW ENERGY

TYPE:	Thermal heterogeneous.
PURPOSE:	Versatile zero energy facility. Lattice testing and oscillator experiments.
LOCATION:	A.E.R.E., Harwell, England.
OPERATION:	Commenced operation July 26, 1954.
FUEL:	Variable. for DIDO, Enriched uranium alloy. Alloy: Uranium-aluminium, aluminium clad. Plateform: 23.6 in. x 2.36 in. x 0.036 in. Curvature: on radius $5\frac{1}{2}$ in. Assembly: 2.9 in. sq. approx., 9 plates per box.
CLADDING:	Aluminium: S I C. Treatment: Al sheet, welded on three sides, rolled.
MODERATOR:	Heavy water—total investment 15 tonnes. Quantity variable—depending on experiment.
CORE:	Variable. Reactor tank 8.5 ft. diameter x 10 ft. high. for DIDO: 34 in. x 28 in. x 24 in. high. Lattice: basically square, central row displaced, 6 in. pitch. Number of fuel elements: 25.
REFLECTOR:	Graphite. Radial thickness: 33 inches approx. Design allows for variation if required.
COOLANT:	Heavy water. Natural convection in moderator.
FLUX:	Maximum thermal neutron flux: 3 x 10° n/cm^{2}-sec. Corresponds to maximum power: 300 watts.
CONTROL:	Shut-off: in two banks, number variable. for DIDO: two banks of 4 each. Material: cadmium tubes, internal and external Al sheath, weighted with stainless steel. Coarse control: height of D_2O. Pump: variable speed and reversible gear pump.
SHIELDING:	Concrete. Thickness: 2 ft.
OVER-ALL SIZE:	22 ft. x 22 ft. x 18 ft. high.

The World's Reactors: No. 3 — NRX

ADDITIONAL DATA

Fuel charge for criticality	— 175 rods, a total of 10 tons.
Maximum fuel temperature	— 1,100°F, (600°C).
Fuel sheath temperature	— 260°F (130°C).
Thermal utilization factor	— 0.928.
Fast fission factor	— 1.036.
Resonance escape probability	— 0.909.

A limited supply of separate copies is available of this series of data sheets on various reactors built or projected throughout the world. Copies may be obtained from the publishers, Temple Press Limited, Bowling Green Lane, London, E.C.1, at the cost of packing and postage only (4d. each).

Scientific Problems in the Development of Nuclear Power*

Further research into the physics, chemical and metallurgical problems of power reactor design will lead to higher burn-up figures, higher temperatures and efficient conversion and breeding. Subjects for future experimentation are discussed in the light of present-day experience.

ALTHOUGH the designs of the C.E.A. stations are much improved over Calder Hall there is still a great deal of scope for research and development. Later types of nuclear power stations, using other types of reactor, present a still wider range of problems. These can be divided conveniently into those of reactor physics, solid state physics and chemistry.

Reactor Physics Problems

The first step in a programme of reactor experiments is to assemble or measure all relevant nuclear data. The second step is to make approximate calculations of the core parameters and then to make exponential experiment assemblies or zero energy critical assemblies. This procedure applied to the gas-cooled graphite moderated reactor has given a lattice pitch of about 8 in., and a uranium rod diameter of about 1 in. The graphite used has a cross-section of approximately 4 millibarns and the canning material is a magnesium alloy-magnox. Rate of heat extraction will be approximately 3 MW per ton. Changes in reactivity in the core determine to a large extent the fuel costs in operating the reactor, the burn-up obtainable being a direct function of these changes. The general course following the loading of a reactor with fresh fuel is a drop in reactivity due mainly to the formation of samarium-149, followed by a rise due to the conversion of U 238 to plutonium-239. As the burn-up proceeds beyond 1,000 MW days per ton the conversion of plutonium to higher isotopes, Pu 240, and Pu 241, becomes important. Plutonium-240 is not fissile by thermal neutrons but is converted to Pu 241 with an absorption cross-section of about 1,200 barns. Pu 241 has a fission cross-section of about 1,000 barns and a capture cross-section to form Pu 242 of roughly 500 barns. These figures, however, are not accurate but an electro-magnetic separator for plutonium isotopes has been built to allow these constants to be determined more accurately. Further experiments are required to determine accurately cross-sections of the long-life fission products and this programme is to be undertaken in collaboration with the Oak Ridge National Laboratory. Because of the increase in neutron energy with temperature of the moderator information is required on the behaviour of materials in neutron fluxes of energies higher than those associated with ambient temperatures.

DIDO will provide a flux of 40 times higher than BEPO and a new fast chopper operating at 48,000 r.p.m. is being built. The flight path of this chopper is 100 m. Experiments up to 100 volts equivalent energy should be possible. A linear accelerator under construction at Harwell will have a beam current of 1 amp. in the pulse and an electron energy of 28 MeV, with a pulse width of 0.2 microsec. and a repetition frequency of 400 cycles per second. The neutron intensity from a heavy target will be approximately 100 times that available from the present 15 MeV linear accelerator and the maximum number of neutrons per second in the pulse is expected to be 5×10^{16}. It is also planned to use a sub-critical assembly of fissile material as a neutron booster to increase the intensity by a further factor of 10.

Another important factor in determining the burn-up in a particular reactor is the cycle of fuel element changes which is adopted. The ideal method is to discharge the fuel elements quasi-continuously and this can be achieved if the reactor designs provide for charge and discharge to be carried out while the reactor is operating. When continuous charge and discharge is not possible operational procedure may lead to discharge by zones so that the maximum irradiation of individual fuel elements may vary appreciably; as a result the average burn-up will be less. Present estimates of burn-up are uncertain by 500 MW days per ton, but a figure between 2,500 and 3,000 MW days per ton can be expected in future power stations. Enrichment of the fuel can increase this figure of burn-up; recent calculations indicate that the cost of enriching the fuel by a small amount in U 235 would be more than balanced by the increase in burn-up possible.

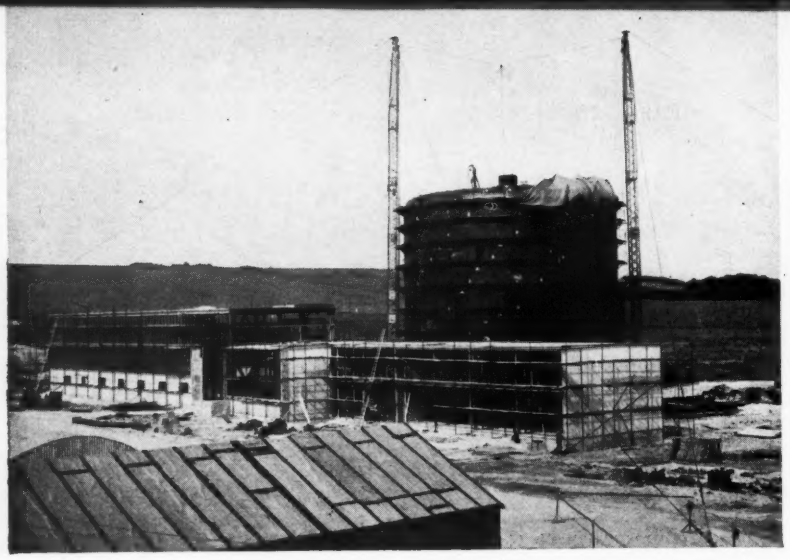
Apart from this initial enrichment burn-up depends upon the conversion factor and upon η, the number of neutrons produced per fissile atom destroyed. With increasing reactor temperature η markly decreases in the plutonium uranium cycle and this can have an important effect in reducing uranium utilization. A gas-cooled graphite-moderated reactor with a conversion factor of 0.8, and an operating temperature of 400°C, could achieve an over-all burn-up of the order of 10,000 MW days per ton. Such a figure cannot be achieved in an enriched fuel reactor such as a sodium-graphite type especially if the operating temperature is about 500°C because η then falls to between 1.65 and 1.70. It would appear that in a sodium-graphite reactor a U 233-thorium cycle is to be preferred. High burn-up of uranium can be achieved in heavy water reactors with a conversion ratio of 0.9 and by using uranium oxide fuel elements, burn-up of well over 10,000 MW days per ton should be achievable.

Theoretical calculations on the parameters in a fast reactor are more difficult to make but the zero energy reactors ZEPHYR and ZEUS, fuelled by plutonium and U 235, respectively, have added considerably to our knowledge. It has been found that fission of U 238 contributes in an important way to the neutron economy of the reactor, and in ZEPHYR breeding gains of over two have been obtained. In future plutonium high-powered reactors conversion gains of 1.6 to 1.7 will be achieved. ZEPHYR has indicated that with a plutonium core and thorium blanket a conversion gain of 1.6 can be expected.

Solid State Physics

Problems of metallurgy in nuclear reactors are even more important than those of nuclear physics. The next graphite-moderated, gas-cooled reactor will operate with a fuel element surface temperature somewhat over 400°C. Sodium graphite reactors and fast reactors have a surface temperature of about 500°C or greater. Low temperature radiation damage is dominated by the distortion of uranium, this problem is still very far from being understood.

**Extract from the opening address by Sir John Cockcroft to the conference on "The Physics of Nuclear Reactors" held by the Institute of Physics (in conjunction with the B.N.E.C.) from July 3-6. The full text will be included in a special supplement to the December issue of the British Journal of Applied Physics.*



DIDO—the heavy water high flux research reactor nearing completion at A.E.R.E., Harwell. DIDO is expected to undergo criticality tests later this month and when in full operation will provide facilities for irradiation experiment and radio-isotope production.

The present solution is to heat-treat the metal so as to reduce the grain size and obtain random orientation of the crystals in wrought bars. As a result the limiting factor for burn-up in the C.E.A.'s initial reactors is unlikely to be the distortion of the uranium rods. At higher temperatures, although the uranium is more pliable, pockets of gas form which cause bulk swelling of the metal. This phenomenon is again only poorly understood but by using a strong canning material the distortion figure can be reduced to about 5%. Radiation effects on graphite have shown that graphite crystals tend to grow in one direction and the result is that bulk graphite grows by .05% during the year in a flux of 10^{13} neutrons/cm^2-sec. at a temperature of 150°C. At the same time striking changes in the physical properties such as thermal conductivity occur. Energy is stored in the interstitial atoms so that at a temperature of 100°C and an irradiation of one year at 10^{13} n/cm^2-sec., the stored energy is 110 calories per gram. At 30°C it is 190 calories per gram. A large part of this energy can be released by heating the graphite above the irradiation temperature; the graphite specimen will then show quite spectacular spontaneous heating.

Chemical Problems

An important section of the chemical problems is associated with compatibility between the fuel, moderator and the canning materials and coolant. In the gas-cooled, graphite-moderated reactor the principal compatibility problem is that of CO_2 coolant with the graphite moderator. The reaction rate increases with radiation and a loop has been operating for some time in BEPO, to study the magnitude of the irradiation effect. The results have shown that with the graphite temperature expected in the Calder Hall and the first C.E.A. reactors the effects are not likely to be significant, but they may prove to be a limiting factor in raising the temperature of the reactor core much beyond 400°C. For higher temperature with CO_2 as coolant it will be necessary to find some means of sealing the pores of the graphite.

In water-moderated reactors the principal problem is the compatibility of the hot water with the uranium fuel. Experiments indicate that the preferred system is to use sintered uranium oxide fuel elements. Compatibility must also be achieved with the pressure vessel. The use of stainless steel throughout is expensive and difficult to decontaminate from fission products, but it may be possible, as a result of loop tests, to use mild steel. In sodium graphite reactors the sodium is compatible with uranium but must be prevented from penetrating the pores of the graphite by, for example, canning the graphite in zirconium. In these circumstances the oxygen content of the sodium must be kept to below 10 parts per million and this may force the designer to use a calandria form for the reactor core.

Recycling of the fuel in solid fuel reactors raises a number of extraction problems. Classical aqueous-solvent techniques are likely to achieve low separation costs of the order of £1,000 per ton of uranium metal processed, compared with an initial fuel element cost of £15,000 to £20,000 per ton. With the greater frequency of processing likely to be necessary in fast breeder reactors investigations are under way to treat the elements (without cooling) by pyro-metallurgical processes.

Problèmes scientifiques du Developpement de l'Energie Nucléaire

Dans un réacteur nouvellement chargé il se produit rapidement un abaissement de la réactivité par suite de la formation de Samarium-149 suivi d'une élévation due à la conversion du U 238 en Pu 239. Après une consommation de 1000 MW jours par tonne, la conversion du plutonium en Pu 240 et Pu 241 devient importante. Le Pu 240 n'est pas fissible par les neutrons thermiques mais se convertit en Pu 241 avec une section transversale d'absorption de 1200 barns. Le Pu 241 a une section transversale de fission d'environ 1000 barns, et une section de captation de 500 barns. Ces chiffres ne sont qu'approximatifs et il a été construit un séparateur électromagnétique en vue de les calculer de façon plus précise. Un autre facteur important de la détermination de taux de brûlure est le cycle de chargement et de déchargement des éléments combustibles. Idéalement, cele devrait se produire de façon continue mais là où la continuité du chargement et du déchargement n'est pas possible on applique le principe de déchargement par zones.

Wissenschaftliche Probleme bei der Entwicklung der Ausnutzung von Atomkräften

Wenn ein Reaktor frisch aufgefüllt ist, beginnt sehr bald ein Nachlassen in der Reaktivität hervorgerufen durch die Bildung von Samarium-149; es folgt danach ein Wiederanstieg infolge der Umwandlung von U 238 in Pu 239. Bei einem Verbrauch von 1000 MW-Tagen je Tonne wird die Umwandlung von Plutonium zu Pu 240 und Pu 241 wichtig. Pu 240 kann von thermischen Neutronen nicht gespalten werden, wird aber umgewandelt zu Pu 241 mit einem Absorptionsquerschnitt von 1200 barns. Pu 241 hat einen Spaltungsquerschnitt von etwa 1000 barns und einen Einfangsquerschnitt von 500 barns. Diese Zahlen sind angenähert; ein elektromagnetischer Separator ist konstruiert worden, um die Werte genauer bestimmen zu können. Ein anderer wichtiger Faktor für die Bestimmung des Verbrauchs ist der Verlauf des Einsatzes und der Entfernung von Brennstoffelementen. Ideal wäre fortlaufende Füllung und Entfernung, jedoch muss, wo dies nicht möglich ist, zonenweise Entfernung angewendet werden.

Problemas Científicos en el Desarrollo de la Energía Nuclear

En un reactor recientemente cargado se produce un descenso en reactividad debido a la formación de "Samarium-149" seguida de una alza debida a la conversión de U 238 en Pu 239. Después de 1000 MW días por tonelada de consumo, la conversión del plutonio en Pu 240 y Pu 241 llega a ser importante. El Pu 240 no es fisionable por neutrones térmicos pero se convierte a Pu 241 mediante una absorción variada de 1200 barns. El Pu 241 tiene una sección fisión transversal de alrededor de 1000 barns y una sección transversal de captura de 500 barns. Estas cifras son solamente aproximadas pero se ha construido un separador electro-magnético con el fin de determinar dichas cifras de manera más exacta. Otro factor importante en la fijación de la quema es el ciclo de carga y descarga de elementos de combustible. Sería ideal que esto se produjese de manera continua, pero cuando la carga y descarga continuas no son posible es aplicable la descarga por zonas.

The Fuelling of Nuclear Reactors

by

F. W. FENNING, B.A.

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In a reactor system neutrons are produced, heat is liberated, fuel is burnt and further fuel may be produced. These functions are necessarily interrelated and the choice of a particular reactor system will depend upon the material available and the ultimate purpose of the reactor.

As neutron interactions with nuclei are the source of nuclear energy, a measure of the probability of such interactions is the first requirement. This probability is usually expressed by a cross-section, a target area presented by the nucleus to the neutron for a particular interaction process. For example, the cross-section for fission of U 235 by a neutron of velocity 2,200 m/sec. has been found to be 590×10^{-24} cm^2/nucleus, i.e., 590 barns. Alternatively, this cross-section may be multiplied by the number of nuclei in a gram of U 235 to obtain the so-called "macroscopic" cross-section at 1.51 cm^2/g.

Neutrons may also be captured without causing fission, or scattered by U 235, so that a total cross-section and separate partial cross-sections representing probabilities of the various processes occurring, can be given. The small Greek letter σ is usually adopted for the nuclear cross-section, and the capital Σ for the macroscopic cross-section. For the example of U 235, then, for neutrons with a velocity of 2,200 m/sec.

σ (fission)	=	590 barns
σ (capture)	=	108 barns
σ (scattering)	=	8 barns
σ (total)	=	706 barns
Σ (fission)	=	1.51 cm^2
Σ (capture)	=	0.27 cm^2
Σ (scattering)	=	0.02 cm^2
Σ (total)	=	1.80 cm^2

Cross-sections may vary considerably with the energy of the bombarding neutron, the general form being represented by Fig. 1. In practice the peaks in the cross-section curve, the resonances, may be extremely important, as shown for U 238 in Fig. 2, or non-existent as, for example, in boron-10 in the energy range covered in Fig. 3. Two important fission cross-section curves are shown in Fig. 4, where U 235 is compared to U 238. The former is fissile at any energy of bombarding neutron, while the latter is only fissile at high neutron energy, and then the cross-section is low.

In thermal neutron reactors, the neutrons have what is nearly a Maxwell distribution of energies, with a most probable velocity of 2,200 m/sec. if the moderator temperature is 20°C. This velocity has therefore been adopted as a standard to which cross-sections and fluxes are often referred. However, it is important to realize that the moderator temperature changes the neutron velocity distribution. As reaction rates are the product of flux and cross-section, no error is introduced at other temperatures by using standard values if the nucleus considered has a cross-section which varies inversely as neutron velocity.

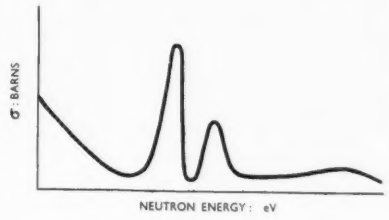


Fig. 1. General form of cross-section curve.

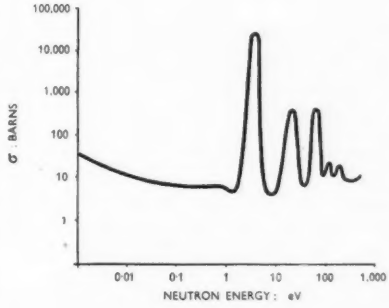


Fig. 2. Total cross-section of U 238 as a function of neutron energy.

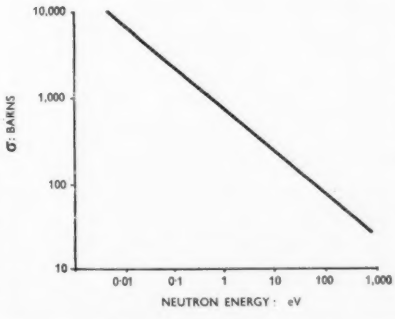


Fig. 3. Total cross-section of B 10 as a function of neutron energy.

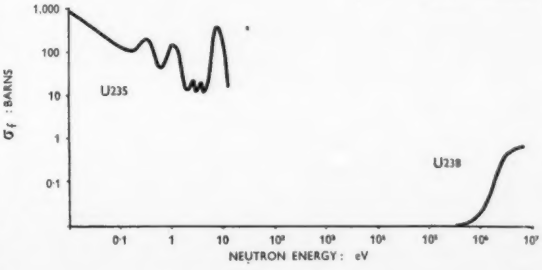


Fig. 4. Fission cross-sections of U 235 and U 238.

Neutron Flux

The second quantity dictating the rate of nuclear reaction must clearly be the number of neutrons falling on the reacting nuclei. In any reactor, neutrons have a wide range of velocities and directions, and the number ϕ falling on a square centimetre in a second, regardless of direction, is the neutron flux. If there are n nuclei per cubic centimetre whose cross-section is σ, then the number of interactions per second will be $n\sigma\phi$ where σ must be appropriate to the neutron velocity to which ϕ refers. If many velocities are present then σ and ϕ must be averaged over all velocities present.

Fuel Rating

To the operating engineer, the rate of heat liberation from the reactor fuel is the important operating quantity. This must obviously be related to neutron flux and fuel cross-section for fission. Each fission yields about 200 million electron-volts; or in other units, 3.1×10^{10} fissions per second yield heat at a rate of one watt. If, therefore, a heat output of one megawatt is obtained from each kilogram of fissile material in a nuclear reactor, the flux ϕ is readily deduced from the relation already presented above; that is, the number of fissions per second must be 3.1×10^{16} and this must be equal to $n\sigma\phi$. Inserting the figures given, a rating of 1 MW/kg of U 235 corresponds to a thermal neutron flux of 2.05×10^{13} n/cm^2-sec. Since a metric ton of natural uranium contains 7.14 kg of U 235 the heat rating and flux relation for a

natural uranium-fuelled reactor can be derived. A rating of 1 MW/tonne of natural uranium corresponds to a thermal neutron flux of 2.88×10^{12} n/cm²-sec.

For reactors operating on other fuels or at other neutron energies the corresponding quantities can be deduced from the appropriate cross-section, e.g., in a fast reactor burning Pu 239 at about 100 keV neutron energy the fission cross-section will be about 2 barns. The fast neutron flux at 1 MW/kg of Pu 239 will then be 6×10^{15} n/cm²-sec.

Total Fuel Requirement

The fuel requirement for a given electrical output follows. An example will be taken in which it is required to generate 1,000 MW of electricity at an efficiency of 25%. 4,000 MW of heat are required for which $4{,}000\times10^{6}\times3\times10^{10}$ fissions per second must take place; that is 1.2×10^{20} per second. This corresponds to 1.5 tonnes of uranium or plutonium to be fissioned every year, or, in a thermal reactor, about 1.8 tonnes destroyed per year, since some is destroyed by neutron capture and does not undergo fission.

In order to be able to burn that amount of nuclear fuel, several reactors may be required, and the amount which must be present in the reactors will depend on the fuel rating. If the mean rating is 1 MW/kg of U 235 (a mean thermal neutron flux of 2.05×10^{13}n/cm²-sec.) then 4,000 kg=4 tonnes of fissile material must be present in the reactors.

As pure fissile material (U 235, Pu 239 or U 233) this is a formidable requirement, but as natural uranium it represents about 600 tonnes, which is quite small compared to the world's annual output. Noting these required annual consumptions and initial investments, it is possible to state some essential characteristics of the fuel cycles to be adopted. These are: (1) that a large proportion of the nuclei undergoing fission must be the more abundant fertile nuclei U 238 or Th 232. This is most readily accomplished by conversion to Pu 239 and U 233 respectively by neutron absorption; (2) that to keep capital investment down, and fuel consumption costs low, a natural uranium reactor with a natural uranium feed is required. This means that the first nuclear power plants will be based on thermal neutron reactors, since it is impossible to start a fast reactor on natural uranium.

$$U\,238+n\rightarrow U\,239\ \beta\rightarrow Np\,239\beta\rightarrow Pu\,239$$
$$Th\,232+n\rightarrow Th\,233\beta\rightarrow Pa\,233\ \beta\rightarrow U\,233$$

The conversion factor of such a reactor is defined as the number of new fissile nuclei produced for each fissile nucleus destroyed. Theoretically, maximum values for this conversion factor can be deduced from the experimentally-determined values of η, the number of neutrons produced when a fissile nucleus is destroyed. Clearly, as one neutron is used in destroying the fissile nucleus, the maximum possible value of C, the conversion factor is $C=\eta-1$. In practice there is an appreciable probability that the fertile material will undergo fission with a fast neutron interaction without the intermediate step of conversion. This is taken into account by the so-called "fast fission factor," ϵ, by which η must be multiplied. Also, some neutrons will inevitably be lost by absorption in moderator, canning material, coolant, fission products or by leakage from the reactor. It follows that in practice $C<\epsilon\eta-1$.

The experimental values of η are given in Table 1 for three neutron

TABLE 1

Experimental Values of η

Neutron Spectrum	Fissile Isotope		
	U233	U235	Pu239
Cold thermal	2.29	2.07	2.03
Hot thermal	2.29	2.03	1.90
Intermediate	Unknown	1.7	1.6
Fast	2.4	2.3	2.8

energy spectra, loosely called thermal, intermediate and fast. Values of ϵ can vary between 1.0 for a heavy-water-moderated thorium system to 1.1 for a natural water-moderated U 238 system. Both systems can be called thermal. In fast reactors ϵ could be much higher, depending on the arrangement of the fuel.

Classification of Reactors

Reactors are often classified according to the fissile-fertile combination used, and the conversion factor obtained. Terms used are not yet universal, but the following definitions are suggested.

Converter. A converter is a reactor which is fed with one fissile species and by neutron absorption in a fertile material produces another fissile species.

Breeder. A breeder is a reactor which is fed with a fissile species and by neutron absorption in a fertile material produces the same fissile species.

Both categories of reactor can have conversion factors less than, equal to or greater than unity, and are then referred to as having a negative gain factor, as being self-sustaining or as having a positive gain factor. Table 2 summarizes these suggested terms.

TABLE 2

Fissile	Fertile	
	U238	Th232
U233	Converter	Breeder
U235	Converter	Converter
Pu239	Breeder	Converter

Fuel Enrichment

This quantity is simply a measure of the fissile to fertile ratio in the reactor fuel. In the case of a U 235-U 238 mixture, the quantitative definition can be stated as a factor referred to natural uranium as unity. Thus a mixture containing 14 kg of U 235 per tonne of uranium would be described by E=2.

When U 233 or Pu 239 are used, perhaps with fertile material already containing U 235, it becomes necessary to state enrichment in atomic proportions of each component, since the value of the fissile materials to different reactors will not be the same.

Reactor Design and the Fuel Cycle

Both E and C as defined above will depend on reactor design. Both are affected by the amount of neutron absorbing materials required as coolant, moderator or structural materials. Also, as both U 238 and Th 232 absorb neutrons at all energies, E can depend very much on the amount of moderator present. This dependence is implied in the earlier remark that a fast reactor could not be started on natural uranium.

There is therefore a necessary interdependence of E and C through satisfying a neutron balance equation. For whatever is done in reactor design, there must always be one neutron left after each neutron cycle to maintain the chain reaction. Consequently, in trying to meet the two fuel-cycle conditions postulated above, some compromise may be required. To meet the first condition of burning fertile material, a high value of C is required. In achieving this, E may increase as, for example, in a fast reactor in which, as can be seen from Table 1, it is most likely that the highest value of C will be obtained.

Nuclear reactors can be designed for one or more of four purposes. These are (a) as an instrument of research, (b) as a producer of material, e.g., Pu 239, U 233 or radio-isotopes, (c) as a producer of electrical power, (d) as a source of motive power. Because of these different objectives, different fuel and moderator combinations may be desirable.

(a) The first research reactors were of necessity built to use natural uranium. Since research usually requires the highest possible neutron flux with the minimum heat to dispose of, this led to a strong preference for heavy water moderation, as heat output is the product of neutron flux and fissile content, so that for a given flux, minimum heat disposal is obtained with minimum fissile investment.

With heavy water, a natural uranium reactor containing about 5 tonnes of uranium (i.e., 35 kg of U 235) is possible, but with graphite about 25 tonnes (i.e., 175 kg of U 235) is required. It follows that even with the same cooling

arrangement, a flux five times greater for a given heat output is possible in the heavy water case.

While only natural uranium was available, heavy water and graphite were the only moderators of any consequence (beryllium is still too scarce). Now that enriched uranium is available, ordinary water becomes a third possibility, as the neutron absorption in hydrogen is less important. The minimum U 235 requirements for a high flux reactor are 2.5 kg in heavy water, 5 kg in ordinary water, and about 8 kg in graphite, and so heavy water retains its preferred place.

(b) For the production reactor, the outlook is different. Production requires neutrons, and these are produced in fission, and so the maximum heat output is required. Flux level only becomes important where high specific activity isotopes are required, or economic reasons dictate a low fuel and source material investment.

With only natural uranium available, most of the spare neutrons inevitably go to produce plutonium. If some other product is required, "spare" neutrons must be diverted from the moderator, coolant and canning materials, or neutrons leaking from the system must be caught in a blanket of source material. As heavy water absorbs less neutrons than graphite, it is preferred as moderator in this application. This is because it is possible to increase the amount of moderator present and so reduce "resonance" capture in U 238 without diverting the neutrons to the moderator.

If enriched material is available, the case for heavy water is less strong, but it still has an advantage.

(c) For electrical power generation, the major difference is in the requirement of high temperature in the outgoing coolant. This leads to a requirement for high-pressure vessels with heavy and light water and with gas-cooled graphite reactors. It is still important to have a good conversion factor, because of the need to burn U 238 and Th 232. Consequently, the only difference between a production reactor and a power generating reactor is in the operating temperature and the associated engineering complication.

There is no clear case here for one moderator in preference to another. Ordinary water has the serious drawback of a comparatively high capture cross-section leading to a need for enriched fuel and a loss of neutrons to the water. However, as compared to heavy water in this application, it gains by reducing the neutron leakage from the limited size of pressure vessel which can be made. In addition it becomes necessary to pack the uranium fuel rods very close together, and this increases fast fission in U 238; that is, ϵ increases and more neutrons are available. On balance, then, ordinary water is cheaper, can produce a similar conversion factor to heavy water, but requires initial enrichment of the fuel.

(d) Finally, in the mobile reactor application, weight and size are all important. Since the weight is predominantly in the shield of the reactor and the shield is of fixed thickness almost independent of core size, this reduces to the requirement of smallest possible reactor. The order of preference now changes because, although a larger fissile investment is required, the dimensions of an ordinary water system can be appreciably smaller than a graphite or heavy water system. Moreover, the required heat output is often greater than can be extracted from the minimum fuel requirement, and so with highly-enriched fuel the poorer moderator may well be preferred.

The Approach to Full Utilization

It is now possible to return to the question of high fuel utilization. The highest conversion factor is required and from Table 1 the order of preference from this point of view is:

(1) Pu 239 in a fast reactor with U 238.
(2) U 233 in a thermal reactor with Th 232.
(3) U 235 and Pu 239 in a thermal reactor with U 238.

In practice, U 233 and Pu 239 can only come by converting U 235, and so at present the U.K. nuclear programme must begin with (3). With these reactors, conversion factors in excess of 0.9 are unlikely, and so the fraction of natural uranium which can be burned in them is unlikely ever to exceed a few per cent. This means that to cause 1.8 tonnes to be burned as required in our example, the throughput must be about 100 tonnes.

Chemical processing of the discharged fuel will yield Pu 239, and its use in (1) or in a converter with thorium for (2) will enable a gradual approach to 100% utilisation. The alternative to this would be to separate the U 235 from natural uranium by the use of a diffusion plant, and then convert this to Pu 239 or U 233 in a suitable converter.

Le Ré-approvisionnement en Combustible des Réacteurs Nucléaires

On y traite de la physique régissant la considération progressive du plein emploi de l'uranium et du thorium naturels dans un programme de réacteurs d'énergie. Dans un réacteur, il se produit des neutrons, de l'énergie est libérée, du nouveau combustible se forme et du combustible se brûle. L'optimisation de ces divers paramètres entraîne une variété de dessins de divers réacteurs pour une variété de buts. Chaque fission donne environ 200 meV et 1 watt est ainsi produit par $3{,}1\times10^{10}$ fissions par seconde. D'un examen de la section du neutron un taux de 1 MW par kilog de U 235 correspond à un flux de neutrons thermique de 2×10^{13} n/cm²-sec. Un calcul analogue nous donne le flux de neutrons rapides à un taux de 1 MW par kilog de Pu 239 comme 6×10^{15} n/cm²-sec. Des calculs du taux de brûlure des matières fissibles dans un réacteur montrent que l'emploi de substances fortement enrichies n'est pas pratique pour des raisons économiques mais une alimentation en uranium naturel est une base satisfaisante pour un programme de réacteur.

Brennstoffe für Atomkernreaktoren

Die physikalischen Grundlagen für den allmählichen Aufbau bis zur vollen Ausnutzung natürlichen Uraniums und Thoriums im Bauprogramm von Atomkraftwerken werden diskutiert. In einem Reaktor werden Neutronen erzeugt, Energie wird frei, neuer Brennstoff formt sich und der Brennstoff wird verbrannt. Um das Optimum aus all diesen mannigfaltigen Faktoren zu erzielen, hat man verschiedene Konstruktionen von Reaktoren je nach dem verschiedenen Zweck. Jede Spaltung eines Atoms bringt ungefähr 200 MeV und daher wird ein Watt bei der Spaltung von $3{,}1\times10^{10}$ Atomen je Sekunde erzeugt. Wenn man den Neutronenquerschnitt in Rechnung stellt, dann entspricht einer Leistung von 1 MW je kg U 235 ein thermischer Neutronenstrom von 2×10^{13} n/cm² sec. Eine ähnliche Rechnung ergibt einen schnellen Neutronenstrom von 6×10^{15} c/cm² sec. bei einer Leistung von 1 MW je kg Pu 239. Berechnungen hinsichtlich der Grösse des spaltbaren Materialverbrauchs in einem Reaktor ergeben, dass die Verwendung stark angereicherten Materials aus wirtschaftlichen Gründen unpraktisch ist, dass aber die Zufuhr natürlichen Uraniums eine genügende Grundlage für die Anfstellung eines Reaktorenprogramms bietet.

Aprovisionamiento de Combustible de Reactores Nucleares

Los principios físicos que gobiernan el acercamiento progresivo al pleno uso del uranio y torio naturales en un programa de un reactor generador, se discuten aquí. En un reactor se producen neutrones, se descarga energía, se crea combustible adicional y se quema el combustible. La optimización de estos varios perámetros da por resultado el diseño de reactores adaptables a distintos fines. Cada fisión rinde aproximadamente 200 MeV y 1 watt es por consiguiente generado by $3{,}1\times10^{10}$ de fisiones por segundo. Del estudio de la sección transversal del neutron una razón de 1 MW por kilógramo de U 235 corresponde a un flujo de neutrón termal de 2×10^{13} n/cm²-segundo. Un cálculo parecido nos produce el flujo rápido de neutrón a razón de 1 MW por kilógramo Pu 239 como 6×10^{15} n/cm²-segundo. Los cálculos de la proporción de quema de material fisionable en un reactor demuestran que el empleo de materiales altamente enriquecidos no es práctico sobre bases económicas pero que la alimentación a base de uranio natural es una base satisfactoria para un programa de reactor.

American Private Research Reactor

The 50 kW homogeneous reactor built by Atomics International for private industrial research is now in operation at the Illinois Institute of Technology. It will be used mainly for irradiation research and on-the-spot production of short-lived isotopes, and will be operated by the Armour Research Foundation for the 24 industrial companies financing it.

SAID to be the first nuclear reactor to be installed in a densely-populated area since the 1941 Fermi unit at Stagg Field, a new homogeneous reactor is in operation in the Armour Research Foundation of Illinois Institute of Technology. It is located in the new Physics and Electrical Engineering Research building at 3440 S. State Street, Chicago. Built by Atomics International, a division of North American Aviation Inc., the reactor is a co-operative venture, 24 industrial companies having participated in the financing of the project.

Each of them will contribute $20,000 towards the estimated cost of $700,000; the remainder will be found by the Armour Research Foundation.

Nominally rated at 50 kW, the reactor will not be used for power production, its purpose being a source of neutron and gamma radiation, for biological studies, radiation effect experiments and neutron diffraction analysis. In addition, work with isotopes having short half-lives will be facilitated with the source of neutrons close at hand. It will, in fact, enable much industrial research to be undertaken which at present is impracticable since military requirements and security restrictions place limitations on access to reactors. The new reactor will be free of all restrictions—other than those called for by technical common sense—and without secrecy of any kind except that normally expected for the protection of an individual company's research programme.

Design Features

The reactor is of the homogeneous type, the fuel being enriched uranium, in the form of uranyl sulphate dissolved in ordinary water. At a nominal rating of 50 kW the maximum thermal neutron flux at the centre of the core is about $1.7 \times 10^{12} n/cm^2$-sec.

The core assembly consists of a stainless steel sphere, 12½ in. outside diameter, carrying vertical sleeves for the four control rods and central exposure tubes extending horizontally through the centre. Cooling coils, a pipe for filling and draining the fuel solution and a gas outlet tube are also fitted. The core is enclosed in a reflector assembly of graphite blocks which form a rectangular prism about 6 ft. 6 in. × 5 ft. × 5 ft. Graphite is AGOT-grade with density of 1.67 gm./cm³ and boron content of less than 0.1 p.p.m.

Below the reactor is the sub-pile, or "utility" room, in which are located the coolant pumps and the gas-handling plant. Cooling is carried out in two stages, the primary coolant being distilled water and the secondary being the ordinary city supply. Although this is completely isolated from the primary coolant it is continuously monitored, so that any leakage causing radioactivity in the secondary water will automatically cut off both supply and drainage systems. The cooling coils in the core consist of ten loops of ¼ in. stainless-steel tubing connected in parallel. Inlet temperature of the primary coolant to the core is 80°F, and outlet temperature is 110°F. A constant-speed centrifugal pump is provided, for an actual flow of 12 g.p.m., the pump rating being 14 g.p.m. at 50 p.s.i. A 5-gal. surge tank tested to 100 p.s.i. is provided.

The main heat exchanger is rated at 14 g.p.m. and has a primary cooling range of 109°F—80°F for a secondary coolant temperature rise of 70°F—89°F. There is in addition a 2 g.p.m. heat exchanger for the recombiner unit which is also cooled by the primary coolant system.

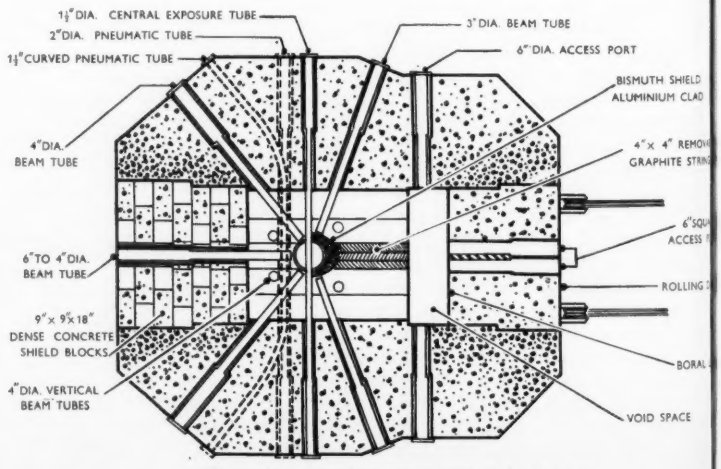
The gas handling system, for the gaseous products of the reactor, operates as a closed system in an atmosphere of oxygen at a pressure slightly below atmospheric. The recombiner, which deals with the hydrogen and oxygen produced by radiolysis of the solution water, has a gas flow rate of 8 cu. ft./min., circulated by a water-operated ejector nozzle, fed at 25 g.p.m. by a "canned-rotor" centrifugal pump. The catalyst consists of ⅛ in. cylindrical pellets of aluminium oxide on which is deposited 0.3% by weight of platinum. The total volume of the system is 30 litres.

Also located in the utility room is the safe-geometry fuel storage tank, which is used for draining the core tank when required. With a capacity of five gallons and constructed of stainless steel it is designed to be sub-critical even when holding all the core solution. Lead bricks are used for shielding the tank.

Four neutron-absorbing control and safety rods are fitted, each 16 in. long × ⅝ in. diameter, of boron carbide enclosed in stainless steel. The rods have a travel of 12 in. and a

COMPANIES FINANCING THE PROJECT

Armour and Company, Chicago.
Aro Equipment Corporation, Bryan, Ohio.
Ball Brothers Company, Inc., Muncie, Ind.
Borg-Warner Corporation, Bellwood, Ill.
Caterpillar Tractor Company, Peoria, Ill.
Clark Equipment Company, Buchanan, Mich.
Deway and Almy Chemical Company, Cambridge, Mass.
Elgin National Watch Company, Elgin, Ill.
Eli Lilly and Company, Indianapolis, Ind.
The Fireston Tire and Rubber Company, Akron, Ohio.
General Portland Cement Company, Chicago.
Gustin-Bacon Manufacturing Company, Kansas City, Mo.
Illinois Tool Works, Chicago.
Inland Steel Company, East Chicago, Ind.
International Business Machines Corporation, New York.
N. W. Kellogg Company, New York.
Kimberly-Clark Corporation, Neenah, Wis.
Nuclear Instruments and Chemical Corporation, Chicago.
Ohmite Manufacturing Company, Chicago.
The Richardson Company, Melrose Park, Ill.
United States Steel Corporation, Pittsburgh, Pa.
Universal Oil Products Company, Des Plaines, Ill.
Victor Chemical Company, Chicago.
Whirlpool-Seeger Corporation, St. Joseph, Mich.

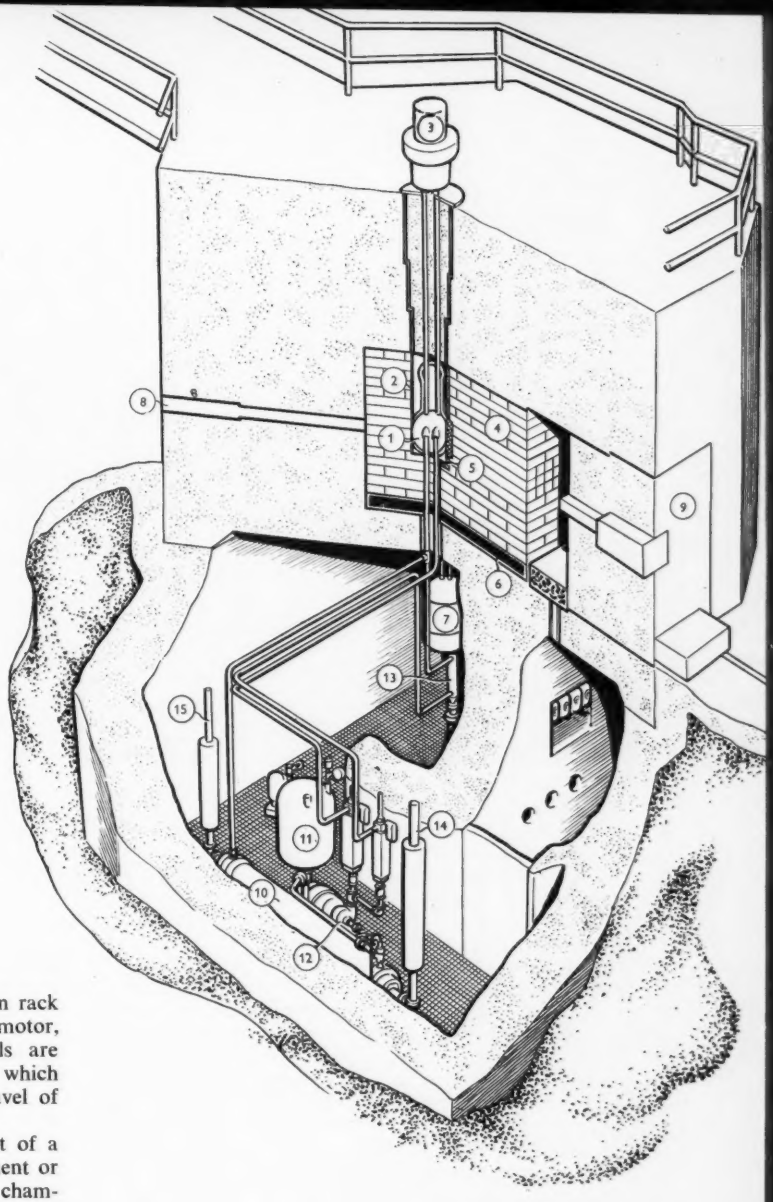

1¼" DIA. CENTRAL EXPOSURE TUBE
2" DIA. PNEUMATIC TUBE
1¼" CURVED PNEUMATIC TUBE
3" DIA. BEAM TUBE
6" DIA. ACCESS PORT
BISMUTH SHIELD ALUMINIUM CLAD
4" DIA. BEAM TUBE
4" × 4" REMOV GRAPHITE STRIN
6" SQU ACCESS
6" TO 4" DIA. BEAM TUBE
ROLLING
9" × 9¾ × 18" DENSE CONCRETE SHIELD BLOCKS
BORAL
4" DIA. VERTICAL BEAM TUBES
VOID SPACE

Plan view showing experimental facilities.

The 50-kW solution-type reactor at the Illinois Institute of Technology.

1. Core tank.
2. Secondary envelope.
3. Control—safety rod drive.
4. Graphite thermal column.
5. Lead shield
6. Ion and fission chamber assemblies.
7. Gas recombiner.
8. Neutron exposure facility.
9. Movable concrete door.
10. Coolant heat exchanger.
11. Surge tank.
12. Pump.
13. Recombiner heat exchanger.
14. Water inlet.
15. Water outlet.

This photograph well illustrates the size of the core.



normal withdrawal rate of 0.1 in./sec., by motor-driven rack and pinion. One rod is driven by a servo-operated motor, and functions as an automatic regulator. All rods are attached to the drive mechanism by electromagnets, which can be released for "scram" shut-down. Free fall travel of the rods is 10 in., with 2 in. air-cushioned travel.

Automatic shut-down would take place in the event of a rise in flux levels, of a breakdown of auxiliary equipment or of a power failure. Power level is measured by fission chambers and γ-compensated ion chambers, and instrumentation for gas handling and cooling systems includes the measurement of sweep-gas flow; core temperature; catalyst-bed temperature; hydrogen concentration; sweep-gas temperature and surge tank level.

Safety

The inherent safety of the reactor was stressed by Dr. R. F. Humphreys (Assistant Director, Armour Research Foundation). The gaseous products of the reactor are confined within a three-fold barrier of the stainless-steel "plumbing," the steel envelope and the reactor room itself, which is designed to be airtight.

Biological shielding of the reactor is provided by a dense monolithic concrete barrier 5 ft. thick. The composition of the concrete is haematite ore, colmanite, mill scale, and Portland cement, the density being 3.5 gm./cm^3. Lead shields and bismuth windows are provided for special purposes as required.

Experimental Facilities

Access to the vicinity of the core is provided by five horizontal beam tubes from 4 in.—3 in. diameter and four 4 in. vertical beam tubes, also two 2 in. pneumatic tubes, one straight and one curved, and a 1½ in. central exposure tube. There is a 5 ft. square horizontal thermal column formed by a square column of graphite in the centre of which are nine removable graphite stringers. A void space is provided between the end of the thermal column and the inner face of a movable concrete door. Four 6 in. access ports open into this space.

Since there is considerable γ radiation produced by the fission products in the gas handling plant, exposure facilities are provided from the sub-pile room to the exposure room. These include two 8 in. and two 4 in. ports, and a rectangular slot 6 in. × 18 in. There are also two 4 in. ports from the sub-pile room to the valve room.

Specification

Design power	50 kW
Zero power critical mass	850 gm. U_{235}
Maximum thermal neutron flux ...	1.7×10^{12}n/cm^2-sec.
Mass coefficient of reactivity ...	0.031%/gm.
Temperature coefficient of reactivity	−0.029%/°C.
Power coefficient of reactivity ...	−0.006%/kW
Fuel solution temperature at 50 kW	80°C
Excess reactivity at 20°C, zero power	3%
Reactivity held in control and safety rods...	8% (2% each rod)
H : U 235 Atomic ratio	350
U 235 concentration	75 gm./litre
Power density, maximum	5.5 watt/cm^3.

Aerial view of construction work in progress at the Meyrin site. The synchro-cyclotron building can be seen in the centre foreground, with the foundations for the proton synchrotron magnet ring in the background.

C.E.R.N.—Eur

Set up in 1954, the Organization's primary object is to provide scope for collaboration between European countries in the field of nuclear research on a large scale. The main effort is being concentrated on the construction of a proton-synchrotron and a synchro-cyclotron.

THE European Organization for Nuclear Research (it has kept the initials of the name used in the preparatory stages, "Conseil Européen pour la Recherche Nucleaire"), consisting of twelve member nations, was formed in September, 1954, primarily to provide scope for collaboration between the various countries in the field of nuclear research on a scale beyond the resources of any individual state. The apparatus needed for the research contemplated is large and costly and the number of highly qualified scientists required implied some measure of international co-operation. The programme as drafted called for the setting up of a body to construct and operate two accelerators—a synchro-cyclotron and a proton-synchrotron, and laboratories with facilities for research on high energy particles. The organization of international co-operation is also a major function and will result in keeping CERN in close contact with all the European markets, giving a choice of the most efficient and specialized suppliers. Finally, the organization is to provide for the training of young technical workers; this group is now in operation in Copenhagen.

CERN is to concentrate solely on research without consideration for any military significance, and it has been stipulated that its work is to be published or otherwise made available. It should be remembered also that CERN was formed by a conference convened by U.N.E.S.C.O. and ties with this organization remain very strong.

The twelve member states accepted the hospitality of Switzerland and constructional work is now in progress at Meyrin. The member states are, in order of the number of representatives, Switzerland with 78, France 67, United Kingdom 42, German Federal Republic 22, Italy 21, Netherlands 14, Belgium 9, Denmark 8, Sweden 8, Norway 6, Yugoslavia 5, Greece 2 and an additional unstipulated 4, giving a total staff at the present of 286. The intention of CERN is to give the opportunity of working on the site at Meyrin to as many scientists as possible, thus drawing on the services of a large and varied number, and the turnover, therefore, will be steady and contracts will usually be for three years. The non-technical staff employed on the constructional work is drawn on the whole from the local areas.

A financial protocol, issued at the time of the formation of the Organization, placed such considerations under a special committee and provided that each member country should contribute in a ratio to its national income. Such contributions are headed by the United Kingdom and France, each of which contributes 23.84%, whilst at the other end of the scale Greece provides 0.97% of the yearly income. The capital proportion is to be revised every three years. The budgetary contributions for 1955 were 25 million Swiss francs and it has been estimated that for 1956 it will be in the region of 34 million Swiss francs, the increase being largely due to the constructional activity and the general move to Meyrin. By the end of 1960 some 197 million Swiss francs (£16 million) will have been spent, and it is estimated that by that time the staff will number 500.

The government of CERN is by the Council, which consists of not more than two delegates from each member state, each with a single vote, under the chairmanship of Sir Ben Lockspeiser, and including such names as Professor J. Nielsen of Denmark, Dr. A. Pennetta of Italy, Professor P. Scherrer of Switzerland and Sir John Cockcroft of the United Kingdom. This Council meets only once or twice a year and as a result a Committee of Council has been formed to meet between sessions. This committee consists of the President of the Council, the two Vice-Presidents, two members of Council—at present representatives of France and the Netherlands—and the chairmen of the Scientific Policy Committee and Finance Committee. The Scientific Policy Committee is advisory and is built up of eight members (irrespective of nationality) under the chairmanship of Professor W. Heisenberg. The Finance Committee has a representative from each state under Mr. J. Willems of Belgium.

The internal organization is under the authority of the Director-General, Professor C. J. Bakker of Zeeman Laboratory, Amsterdam University, the chief executive officer and legal representative. Professor Bakker has succeeded Pro-

fessor Felix Bloch, who held the position until September, 1955. Assisting the Director-General in controlling the general administration are the directors of the six divisions of CERN: the proton synchrotron division, the synchro-cyclotron division, scientific and technical services, site and buildings, theoretical studies and the administration division.

The main effort of CERN has of course been concentrated on the construction of the two accelerators and the general lay-out of the site at Meyrin. The building programme has continued well to schedule. The main structure of the synchro-cyclotron building was completed on time and by the end of 1955 work had begun on the interior and also on the construction of the control station. The construction of the ring and main buildings for the proton-synchrotron is at a less advanced stage, but excavations for the experimental hall, laboratory and ring were completed during 1955.

The theoretical study division is in the Theoretical Physics Institute, University of Copenhagen, and its programme, though mainly that of training young physicists, includes research on problems related to the focusing of ion beams in high energy accelerators, and works in close co-operation with the laboratories of Liverpool University and the Gustaf Werner Institute for Nuclear Chemistry in Uppsala, both of which have put their facilities at the disposal of the Organization. Professor C. Moller is in charge of the division, assisted by Dr. S. Rozental and Dr. A. Bohr. Dr. G. Kallen and Dr. B. R. Mottelson are also full-time senior staff members.

European Organization for Nuclear Research

In addition, a number of bursars from the member states come to Copenhagen for periods usually of one academic year, and leading physicists from outside come to the Institute to give courses of lectures. Representatives of this division have attended such international conferences as those held in Moscow at the beginning of 1955, at Pisa in June 1955, Berne in July and Geneva in August.

Proton-synchrotron

The proton-synchrotron has been designed with a maximum energy of 25 GeV and a maximum magnetic field corresponding to this energy of 12,000 gauss. The machine is built in the form of a ring of 100 metres radius. Recent estimates of the total cost of the project give a figure of 92 million Swiss francs (£7½ million), including the cost of the buildings.

The magnet is divided into 50 magnet periods and 100 magnet units, each unit comprising a focusing sector and defocusing sector. The field index n is quoted as 282 and the operating mode μ is $\pi/4$. Each unit is 4.4 m in length followed by a field-free gap of 1.6 m. Uniformly distributed along the circumference are 10 longer field-free gaps 3 m in length. The total weight of iron in the magnet is 3,200 tons and is in the form of precision stamped laminations of approximately 1 mm thickness, interleaved with paper and bonded with hot setting resin. It is difficult to obtain steel in this quantity with the desired uniformity of characteristics which demands a stringent specification on the figures for coercive force and permeability. These parameters, however, must be stable with time. A considerable amount of effort has been devoted to determining the optimum steels for the purpose and it has been concluded that for satisfactory operation controlled mixing of the laminations is necessary.

Coils of the magnet, if made of copper, would weigh 220 tons, and if of aluminium, 110 tons. The requirement for magnetic field rise time is 1 sec. from the injection field of 140 gauss to the maximum of 12,000. This cycle is repeated every 5 sec. Peak power in the coils is 20 MW and for normal operation a mean power of 1.5 MW is calculated.

Particles are injected at an energy of 50 MeV and receive 50 keV increments in energy per turn. However, 100 keV per turn is available. The peak power in each cavity will be 3 kW and the total weight of ferrite required is 14 tons. A full-scale model of a cavity has been constructed, a wide-band power amplifier having been built for it with a band width of 0.2 to 11 Mc/sec. and with a power output of 4kW at 1 volt rms input.

The vacuum chamber consists of a stainless-steel ring 200 m diameter and with an elliptical cross-section 8×15 cm.

A section of the ring which will house the proton-synchrotron magnets.

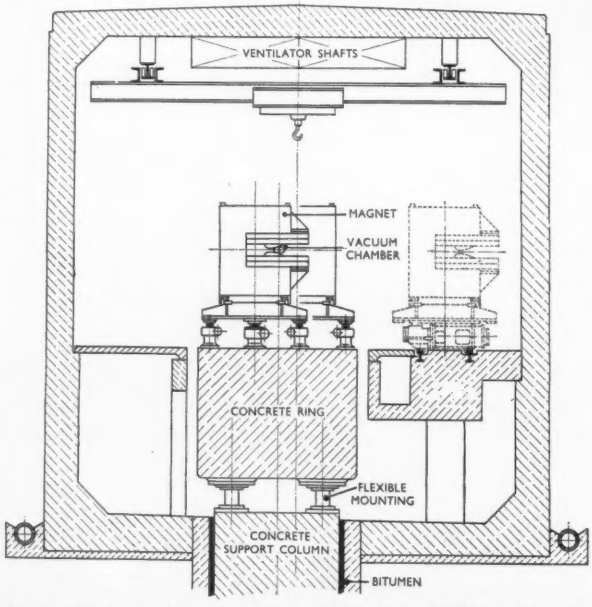
Experimental halls and laboratories associated with the proton-synchrotron.

One of the vertical yoke members of the synchro-cyclotron magnet. The total weight of the magnet will be 2,500 tons. The diameter of the pole discs will be 5 m and the maximum and minimum gaps 45 cm and 36 cm, respectively.

A minimum of 40 pumping stations are arranged around the ring to maintain the pressure at 10^{-5} mm Hg. It is probable that oil diffusion pumps will be employed, as the cooling traps at −80°C required for mercury pumps would present considerable maintenance problems. Getter pumps, which have been under investigation in the United States, and which are to be developed in Europe, have created some interest.

Peak power required by the division is estimated at 12,000 kVa and will be derived from a motor alternator set with a flywheel for energy storage and a mercury arc converter with a peak rating of 34,000 kW. Peak current to be supplied by the converter group will be 5,000 amp. every 3 seconds and 6,400 amp. every 5 seconds.

The erection of the machine, comprising such a large structure, has necessitated the development of original techniques in civil engineering. Foundations consist of 80 cylindrical pillars, 2 m diameter, sunk into the rock structure. The magnets are mounted on a concrete ring 200 m diameter and about 2 m square cross-section, attached to the pillars by a flexible coupling which allows free radial movement but no vertical movement or twist. Detailed examination of the changes in the relative positions of pillars implanted in the superficial layers have shown movements of as much as 1 cm during May-June. Attempts to link these up with meteorological conditions have not been successful.

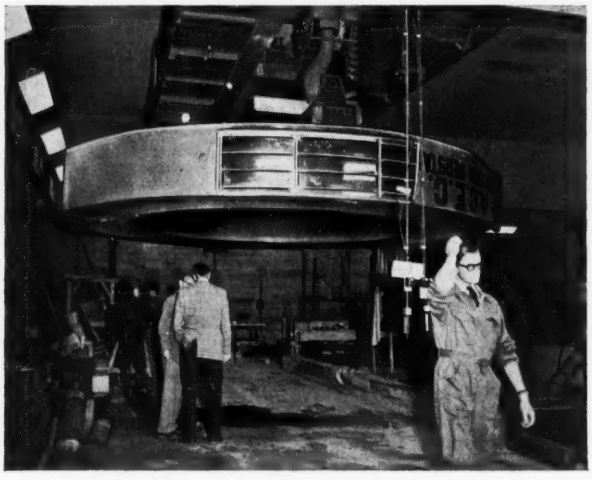


Cross-section of the proton-synchrotron ring building. The rail system on the right allows for removal and replacement of magnet units for servicing.

Synchro-cyclotron

The magnet for the synchro-cyclotron consists of 54 elements, each weighing approximately 46 tons, the pole diameter is 5 m and the minimum gaps 45 and 36 cm respectively. The steel in the magnet is required to have a minimum flux density of 2.03 Wb/m^2 with a field strength of 30,000 At/m. The coils have been designed with a maximum rating of 1.35×10^6 At, each coil being wound with 6,380 m of aluminium conductor forming a double pancake of 37 turns and 333 turns per coil. The outside diameter of these coils is 7.2 m, and their weight 60 tons each.

The vacuum chamber of the machine comprises a nearly square stainless-steel welded tank with sides 5.5 m in length forming a total volume of 23 m^3. The two circular holes



The upper of the two energizing coils for the synchro-cyclotron electromagnet. It is 7.2 m diameter and weighs 60 tons.

5 m diameter which permit entry of the magnet pole tips, are each sealed by special joints. The pumping system comprises three mechanical pumps with pumping speeds of 170 m^3/hr. and two diffusion pumps with pumping speeds of 12 m^3/sec. at 10^{-1}mm Hg. It is anticipated that an ultimate pressure of 3×10^{-6}Hg can be achieved and that a working pressure of approximately twice this figure can be accommodated. Stainless steel has been used in the construction of those parts of the pump near the magnet to avoid distortion of the field. The driving oscillator, with a frequency range of 16.6—28.7 Mc/s is modulated at a repetition frequency of 50 c/s. Frequency control is exerted by a tuning fork system.

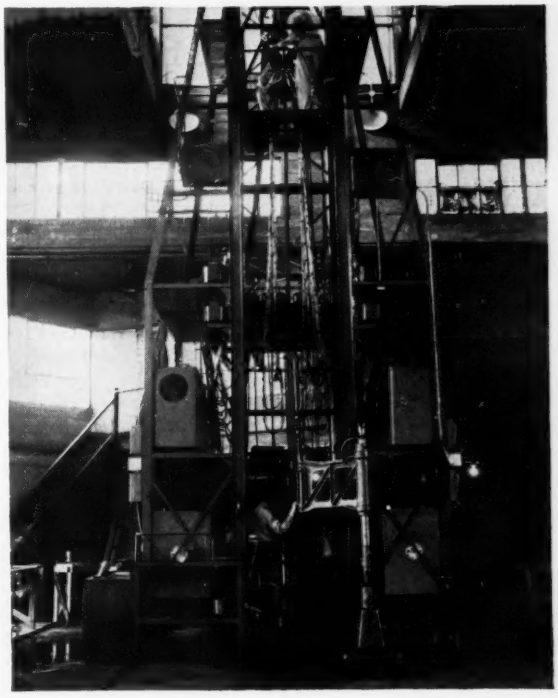
The total power requirement for the machine is approximately 2,500 kVa, derived from a transformer sub-station. Power to the magnet will be taken from a separate 1,000 kW generating set with a capacity of 2,000 amp. at 500 volts. Maximum energy of the protons accelerated by the machine is 600 MeV with an expected internal circulating beam of 1 microamp.

Standardized Heat Exchangers

"Building-Block" Flexibility Claimed for New Alcotwin Unit

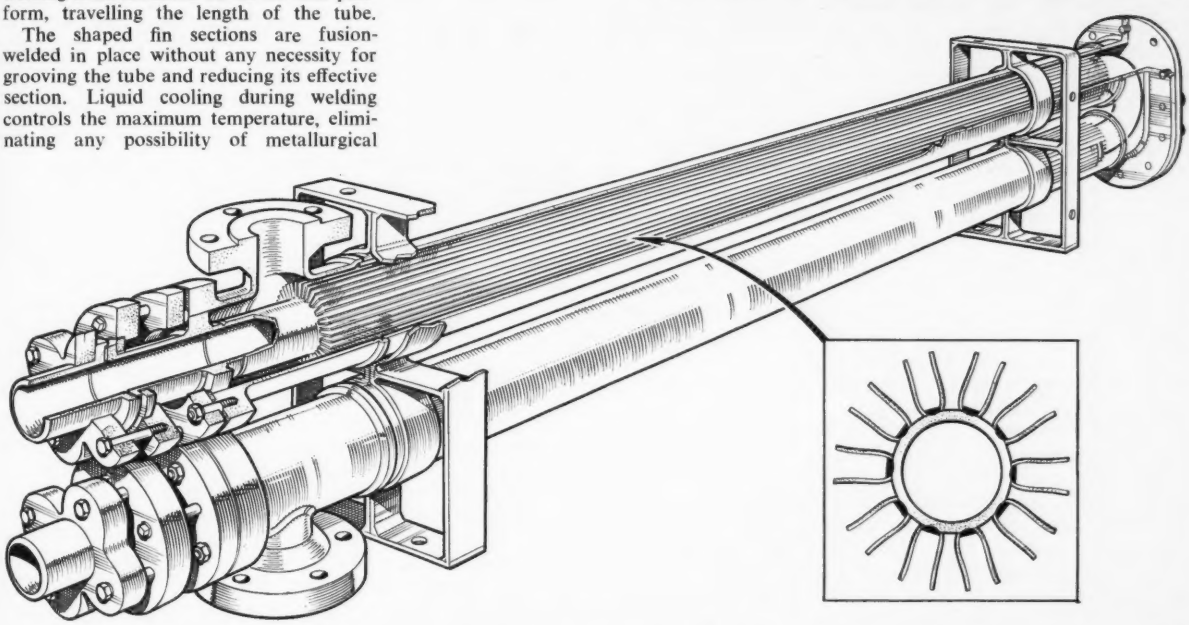
FLEXIBILITY and economy, in addition to high heat transfer performance, are among the advantages claimed for a new double-pipe heat exchanger unit developed by Alco Products Ltd., and manufactured in their plant at Beaumont, Texas.

The basis of the Alcotwin, as the new exchanger is called, is a standardized fin-tube unit, longitudinal fins being permanently bonded to the tube with a continuous weld. The welding process was originally developed by Carter Craft Inc., of Dallas, Texas, to meet A.E.C. requirements for high-quality fin-tubes, and the patent rights were acquired by Alco. The process has been adapted to mass-production methods.



The welding machine developed by Alco Products Inc. for fin-tube production. The tube is held vertically while the welding heads are mounted on an elevator and run the full 3-storey height of the machine.

Below. A cut-away drawing of a typical Alcotwin two-pipe heat exchanger, with an enlarged section of the tube showing the runs of weld metal.



Fin-tube Manufacture

The fins are attached to the tube by heliarc welding and, in the machine developed for the Beaumont plant, tubes and fins are arranged vertically, the machine being three stories high and having the welding head mounted on an elevator platform, travelling the length of the tube.

The shaped fin sections are fusion-welded in place without any necessity for grooving the tube and reducing its effective section. Liquid cooling during welding controls the maximum temperature, eliminating any possibility of metallurgical changes which might affect the corrosion-resisting properties of the material.

The machine will accommodate tubing up to 5 in. diameter, and either ferrous or non-ferrous metals may be used, including stainless steels and various copper alloys. Fins and tubes may be of dissimilar materials, if required, and no intermediate high-resistance bonding materials are used. The one-piece construction gives, it is stated, a permanent contact which is structurally strong and will remain so in spite of repeated heating and cooling.

Unit Design

As will be seen from the accompanying cut-away illustration, the Alcotwin exchanger is of the two-pipe design, which is considered more flexible than the shell-and-tube type. Alcotwin exchangers can, it is stated, be assembled in series-parallel combinations or can be moved about as required to suit changes in process requirements, and tubes can be withdrawn without disturbing pipework, thus considerably facilitating inspection and cleaning. Since the fin tubes are standard, spare parts stocks are reduced.

The end connections, as will be seen from the illustration, are of the three-flange type, so that each joint can be tightened individually to ensure proper tightening and uniform gasket loading.

Mechanical Contactors for Liquid-Liquid Extraction

by

J. D. THORNTON, Ph.D., F.R.I.C., A.M.I.Chem.E.

Chemical Engineering Division, A.E.R.E., Harwell

PART 2

Constructional details are given of various types of experimental contactors which have been used at Harwell. The calculations for the diameter and height of the column-type contactors are summarized.

IN the case of column-type contactors such as rotary annular, rotary disc and pulsed columns, the diameter for a given throughput can be calculated directly from a knowledge of the physical properties of the system, the energy input and the contactor geometry. On the other hand, the column height required for a specific separation is not amenable to direct calculation and it is necessary first to measure the H.T.U. for the system in a small-scale contactor. The data so obtained may then be used to calculate the height of the full-scale unit. At the present time, there is a lack of information on the design and construction of many of the more important types of contactors, and it is the intention of this article to describe a number of experimental contactors which have been used at A.E.R.E., Harwell, to obtain data for the design of radioactive extraction equipment.

Construction of Typical Contactors

Extraction equipment for radioactive processing is normally fabricated from stainless steel, but for pilot or laboratory scale units it is frequently advantageous to use flanged borosilicate glass pipeline for the construction of column-type contactors. Other materials of construction can of course be used subject to the usual corrosion limitations.

Rotary Annular Contactor[5] *(Type IA)*—This is the simplest of the IA type contactors and consists of a column shell fitted with a coaxial rotating cylinder. The shearing forces set up in the annular space between the rotor and the column shell give rise to Taylorian vortices[7] and the high degree of turbulence which results produces a fine phase dispersion. The effects of column geometry and rotor speed upon the performance and throughput of contactors of this type have been investigated by Thornton and Pratt[8] who used columns up to 6 in. in diameter. The construction of a typical experimental unit is shown in Fig. 1.

The column shell is constructed from standard flanged sections of borosilicate glass pipe. The rotor is made from stainless steel and is held in position on the driving shaft by means of locknuts. Quiescent zones are provided at each end of the contactor to facilitate phase separation and so the shearing action is confined to the length of the rotor by fitting stationary sleeves around the ends of the driving shaft as indicated. However, in order to minimize any disturbance of the fluid motion these should be gradually expanded to the rotor diameter. To reduce interfacial disturbances to a minimum, it is also advantageous to fit anti-swirl baffles to the stationary sleeves at the top or bottom of the column, depending upon whether the light or heavy phase is dispersed.

The column rotor is driven by a flame-proof motor and it is preferable to obtain variations in rotor speed by means of an infinitely variable gearbox rather than by varying the motor speed. By this means, a more nearly constant speed can be maintained. The shaft bearings are standard ball races and are carried on brackets external to the column. This is particularly important with glass column shells as this reduces vibration to a minimum. It is preferable to locate the bottom bearing externally to the column, and so the driving shaft is brought through the column base via a stuffing box filled with a suitable packing. If necessary the bottom bearing can be protected further by means of a flinger disc.

When the column annulus is small, it frequently happens that a fraction of the dispersed phase is entrained in the continuous-phase exit stream. This can be overcome by fitting external settlers of conventional pattern or, if the solvent phase is dispersed, by packing the bottom of the column with $\frac{1}{2}$ in. carbon Raschig rings. These are wetted preferentially by the solvent droplets so causing coalescence and subsequent de-entrainment.

Although the rotary annular contactor has the advantage that the column shell can be constructed from non-precision-bore piping, because no internal baffles are fitted inside the column, it does suffer from a severe limitation upon the unsupported shaft length that can be tolerated before the critical whirling speed is reached. If maintenance considerations, therefore, prohibit the use of internal bearings or supporting bushes, the maximum permissible column height is thereby limited. Consequently if a large number of extraction stages are required, it is preferable to consider an alternative form of contactor such as a pulsed column where the height is not limited by whirling speed considerations. (cf. Table II, Part I, p. 160, July.)

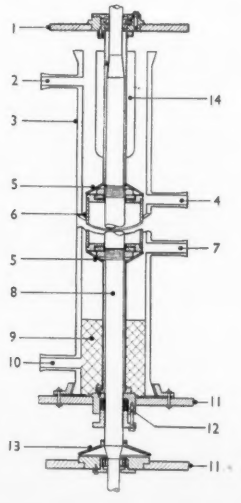
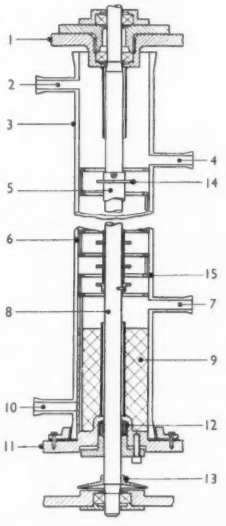


Fig. 1. A typical experimental rotary annular contactor.

1. Top support.
2. Solvent outlet.
3. Column.
4. Water inlet.
5. Conical shields.
6. Rotor.
7. Solvent inlet.
8. Shaft.
9. Carbon rings.
10. Water outlet.
11. Bottom support.
12. Gland.
13. Flinger disc.
14. Baffles.

Rotary Disc Contactor[6] *(Type 1A)*—This differs from the rotary annular contactor in so far as the central rotor is replaced by a driving shaft carrying a number of discs spaced at regular intervals along its length, which rotate at high speed between fixed annular baffles. The enhanced turbulence in the system arises from the constraining action of the baffles upon the vortex flow pattern. For this to be effective, the disc to baffle spacing should be less than the natural vortex height. Taylor[7] demonstrated that the latter is approximately equal to the annular width, and so it follows that higher efficiencies will be obtained when the disc to baffle spacing is less than the annular width. This has been confirmed experimentally by Logsdail and Thornton with a 3 in. diameter unit.[4]



1. Top support.
2. Solvent outlet.
3. Column.
4. Water inlet.
5. Spacer ring.
6. Spacer rods.
7. Solvent inlet.
8. Rotating shaft.
9. Carbon rings.
10. Water outlet.
11. Bottom support.
12. Stuffing box.
13. Flinger disc.
14. Rotor discs.
15. Stator rings.

Fig. 2. Type 1A rotary disc contactor.

A sectionalized drawing of a typical extractor is shown in Fig. 2. The general construction is similar to the rotary annular contactor. The rotor discs, which are a push-fit on the driving shaft, are made from stainless steel and are spaced by suitable lengths of sleeving, the top and bottom discs being held in position by screws. Sleeves are fitted over the top and bottom of the driving shaft in order to provide calming sections for phase separation and if necessary, anti-swirl baffles can be located in the vicinity of the interface. Carbon Raschig rings can be used to prevent the entrainment of solvent droplets in the exit aqueous phase or external settlers can be provided.

There is, however, one important difference between the rotary disc and the rotary annular contactor and this arises from the need for ensuring that the perimeters of the annular baffles make good contact with the column wall. If the baffles are a poor fit due to irregularities in the column diameter, an appreciable fraction of the dispersed phase droplets tends to by-pass the rotor and to film up the wall of the column with a consequent loss in extractor efficiency. If the column shell is made from stainless-steel pipe, uniformity of diameter can usually be guaranteed, and it is not a difficult matter to ensure that the baffles are a good fit. On the other hand, when borosilicate glass pipe is used, the internal diameter can vary appreciably and it therefore becomes necessary to use precision bore tubing.

The annular stator baffles are made from stainless steel and are assembled on three threaded spacing rods, 120° apart. As shown in Fig. 2 the spacing rods are not, however, continuous throughout the length of the column as, under these conditions, the dispersed phase would tend to film up them, so reducing the extraction efficiency. It is therefore preferable to stagger the location of the rods by 60° between adjacent pairs of baffles. The complete baffle assembly is a push-fit in the column shell and rests on either an annular support welded to the inside of the column below the bottom disc or, in the case of a glass column, three supporting legs which are fitted to the bottom baffle as shown. This method of assembly facilitates easy cleaning and is suited to experimental units where frequent changes may have to be made in the baffle spacing.

In the absence of internal supporting bearings the height of the rotary disc contactor, like that of the rotary annular contactor, is limited by critical whirling speed considerations.

Pulsed Column Contactors[2, 11, 13] *(Type 1B)*—The principle of bringing two phases into intimate contact by the use of a reciprocating as opposed to a rotary motion is not new, and was proposed by van Dijck as long ago as 1935. More recently, Thornton[9] has shown that the efficiency of distillation columns can also be increased by the application of pulsing techniques.

Pulsed contactors may be classified as follows depending upon the method of pulsing employed:

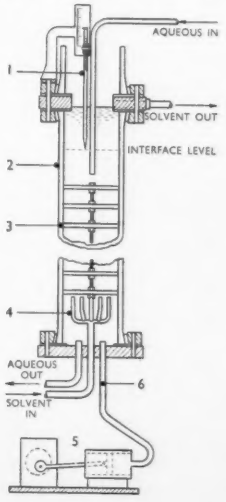
(i) Mechanically pulsed contactors where the process liquids are in direct contact with the pulsing unit or isolated from it by means of bellows or diaphragms, and

(ii) Air-pulsed contactors where the pulsing unit is isolated from the process liquids by a pocket of air or inert gas.

The simplest type of pulsed liquid extraction column consists of a conventional random packed tower connected at its base with a cylinder which is closed by a reciprocating piston. The two phases flow counter-currently through the contactor in the normal way and the frequency and amplitude of pulsation are adjusted to give the required degree of phase dispersion. However, work carried out at Harwell has shown that random packed towers are, in fact, not ideally suited to such purposes as the pulsations cause the packing to orientate. For this reason fixed or regular packing such as corrugated screens[10, 11] or sieve-plates should be used.

A number of types of pulsed columns which have been built at Harwell have been described elsewhere[11] and therefore the present article is confined to the mechanically-pulsed and air-pulsed types of sieve-plate columns.

With mechanically-pulsed columns[2] it is important that the sieve plates make contact with the column at all points in order to prevent the dispersed phase from filming up the column wall, so that if borosilicate pipeline is used for the column, it must be of precision bore. The phase entry and exit nozzles may be made an integral part of the column shell, but a simpler scheme is that shown in Fig. 3 where the dispersed-phase entry and continuous-phase exit lines are brought out through the stainless steel base of the contactor. The continuous phase is introduced at the top of the column through a pipeline which extends below the interface level,



1. Interface electrode.
2. Column.
3. Perforated plates.
4. Solvent entry nozzles.
5. Pump.
6. Pulse line.

Fig. 3. Constructional details of a mechanically-pulsed contactor.

whilst the dispersed phase is withdrawn through an annular stainless-steel ring which is clamped between the top of the precision-bore section and a short additional piece of glass pipeline. The latter need not be of uniform bore and merely serves to ensure that no liquid overflows from the top of the contactor. Such construction has the advantage that it is flexible and allows the effective height of the column to be changed at will.

The sieve-plates are conveniently made from $\frac{1}{4}$ in. thick stainless-steel sheet and each plate is drilled with sufficient $\frac{1}{8}$ in. diameter holes, based on a triangular pitch, to give a total free area of 25%. As the free area of the plate is increased, the pitch of the holes becomes smaller and there is a greater tendency for the dispersed phase droplets to coalesce on the top side of the plates.[12] Although this effect increases the throughput of the contactor, it also reduces the extraction efficiency by virtue of the reduced interfacial area of contact between the phases. In practice, therefore, a balance must be struck between these two effects and the above plate specification can be regarded as approximating to optimum design. In the case of the smaller contactors—below 6 in. diameter—the periphery of each plate is machined until it is a push fit in the precision bore column shell. However, with larger diameter columns it becomes impracticable to produce a glass pipe of uniform diameter, and rolled steel shells frequently have a tendency to be slightly barrel-shaped. For this reason it is more convenient to machine the sieve plates until they are approximately $\frac{1}{8}$ in.-$\frac{1}{4}$ in. under-size and then to weld a grooved rim on to the periphery of each plate into which is fitted a suitable packing material. A typical sieve plate of this type is shown in Fig. 4; this has a diameter of 12 in. and the packing, in the form of a cord, is shown in position on the rim of the plate.

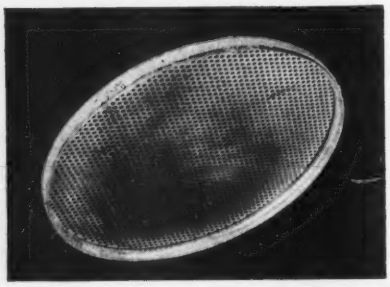


Fig. 4. A 12 in. diameter sieve-plate with welded - on grooved rim into which is fitted a suitable packing cord.

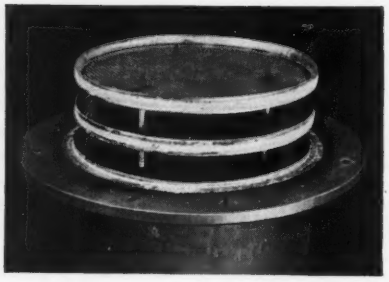


Fig. 5. Method of assembly of a 12 in. diameter column, the plates being separated by spacer sleeves.

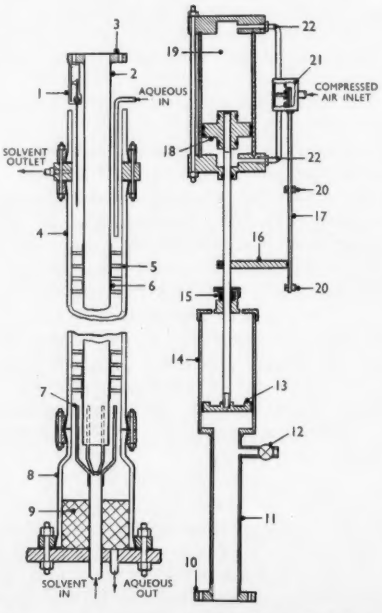
When the sieve-plates are less than 6 in. diameter, it is convenient to assemble them on a central rod and to insert the complete assembly into the column as shown in Fig. 3. The plates are supported on the rod by means of lock-nuts or separated by spacer-sleeves which slip over the rod, and the two end sieve-plates bolted in position. When the column diameter is greater than 6 in., the plates are assembled on three rods in order to give added rigidity. Fig. 5 shows this method of assembly for a 12 in. diameter column in which the plates are separated by spacer-sleeves. Friction alone is usually sufficient to hold the plates in position, but for larger units having diameters greater than 12 in. it is preferable to provide an annular support for the sieve-plate assembly at the bottom of each column section.

The contactor is pulsed by means of a cylinder, closed by a reciprocating piston, which is connected to the bottom of the column. A common device of this type consists of a conventional plunger pump in which the non-return valves have been removed. The column is connected to, say, the outlet of the pump whilst the inlet is blanked off. The advantage of such an arrangement lies in the fact that the amplitude of the pulse can be readily adjusted by means of the usual stroke adjustment on the pump. The frequency of pulsing is controlled by driving the pump through an infinitely-variable gearbox.

Alternatively, the pulsing unit may be driven by a double-acting air motor of the reciprocating type. Such a device is shown in Fig. 6 and will be described later in connection with the air-pulsed column. This arrangement has the advantage of being cheap and relatively simple. The pulse amplitude is controlled by the spacing of two stops on a rod operating the push-pull valve admitting air to the system whilst the frequency is readily adjusted by a throttle valve in the air supply to the unit. However, this type of pulsing system does not exhibit such a clearly defined waveform as a mechanically driven unit and allowance must be made for this in design. The effect of pulse waveform on column throughput and extractor efficiency is important and is discussed further below.

When a valveless displacement pump is used for pulsing the column, the frequency is readily determined from the speed of the driving shaft by means of a tachometer, as in the case of the rotary contactors described above. When the motion is entirely reciprocatory as with the air pulser, the frequency can be measured by arranging the cam (16) on the connecting rod between the two air cylinders (19) and (14) to operate a trip counter. On the other hand, the accurate measurement of pulse amplitude is more complex and is most readily carried out by capacity or conductivity methods.[11]

Whilst mechanically-pulsed columns do not suffer such severe restrictions on height as do rotary type contactors, they are nevertheless limited by virtue of the fact that if large heights of liquid are pulsed at higher frequencies, the pressure at the pulsing unit may become less than the vapour pressure



1. Interface electrode.
2. Dip pipe.
3. Flange.
4. Column.
5. Sieve plate.
6. Spacer rings.
7. Solvent entry nozzles.
8. Bell end.
9. Carbon rings.
10. Flange.
11. Pulsing line.
12. Valve.
13. Secondary piston.
14. Secondary air cylinder.
15. Packing.
16. Cam.
17. Valve arm.
18. Primary piston.
19. Primary air cylinder.
20. Stops.
21. Push-pull valve.
22. Air ports.

Fig. 6. One form of air-pulsed contactor with the pulsing unit driven by a double-acting air motor.

of the process liquor and cavitation or "hammer" will result. This possibility can be minimized by ensuring that the frictional losses in the line connecting the pulsing unit to the column are as small as possible.

The mechanically-pulsed column is not ideally suited to handling highly corrosive or radioactive systems because of maintenance difficulties arising from the fact that the process liquors are in direct contact with the pulsing unit. These difficulties can be overcome in part by isolating the pulsing unit from the column liquors by means of diaphragms or bellows. However, these devices are always liable to fracture and it is better to locate the pulser hydrodynamically above the level of the liquor in the column, so that the pulse is transmitted via a pocket of air or inert gas. Such a system is termed an air-pulsed column[11, 13] and one arrangement is shown in Fig. 6.

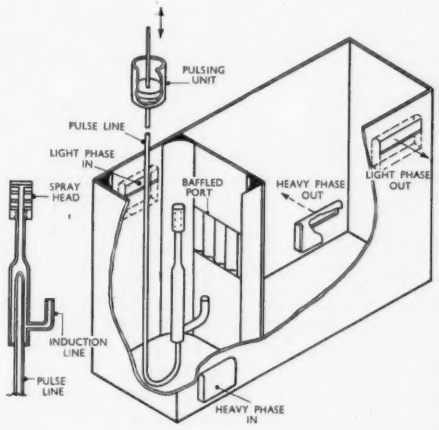


Fig. 7. An air-pulsed mixer-settler unit.

The column is constructed from precision-bore borosilicate glass pipe. The entry and exit process lines are introduced as shown and the bottom section of the column may be packed with carbon Raschig rings in order to eliminate entrainment of the dispersed phase, although this is not normally necessary with pulsed contactors of this type. A dip tube (2) runs concentrically down the length of the column, the bottom being open whilst the top terminates in a flange (3). The pulsing unit consists of a stainless-steel cylinder (14) closed by a reciprocating piston (13). The bottom of the cylinder is connected to a length of stainless-steel pipe (11) which terminates in a flange (10). The cylinder can be vented via the valve (12) when necessary. The piston is driven by a double acting air motor, details of which are also shown in Fig. 6. Compressed air is admitted to the slide valve (21) and enters the primary cylinder (19) through ports (22). As the piston (18) is displaced, the cam (16) operates the slide valve whenever it comes up against either of the stops (20). The pulsing unit is connected to the column by the flanges (3) and (10). The pulse is then transmitted to the column by the air or inert gas which is trapped between the liquor in tube (2) and the piston (13). The sieve plates (5) are of annular construction and are supported at 2 in. intervals along the dip tube (2) by means of spacer rings (6) as shown in the diagram.

An alternative method of air-pulsing the column is to locate the pulse line outside the column shell. In this form the contactor is analogous to the mechanically-pulsed column described earlier except for the fact that the pulsing unit is located above instead of below the liquor level in the column. When the volume of liquid displaced per pulse in the pulse line is large, it is advisable to incorporate an expansion chamber in the pulse line below the pulsing unit, and at the same height as the liquid-liquid interface. This reduces the vertical movement of the liquor in the upper part of the pulse line and so prevents contamination of the pulsing unit.

The maximum permissible height of an air-pulsed column is not limited by cavitation considerations, as is the height of a mechanically-pulsed unit, as the column can be regarded as being permanently cavitated. Power costs may however set a limit to the size of column that can be pulsed economically by this method.

Pulsed Mixer-Settlers[15] *(Type IIB)*—Like pulsed columns, this type of mixer-settler can be pulsed directly or via an air or gas pocket. A drawing of a single unit is shown in Fig. 7. Each unit is made from stainless steel and is divided into a mixing and a settling chamber by means of a partition. A baffled port in the latter enables the mixed phases to pass from the mixer into the settler. Each settler has two exit ports, one for the light and one for the heavy phase, which communicate with the mixing chambers of the two adjacent units. The ejector system, which replaces the conventional impeller, is suspended in the mixing chamber by means of the pulse line which in turn passes through the lid of the unit (omitted in Fig. 7 for clarity).

The ejector is made from stainless steel and is conventional apart from the spray head and the induction pipe which is shaped as shown. The former consists of a hollow cylinder, closed at one end, which is connected to the discharge side of the ejector and which has a number of holes drilled tangentially in the side. These impart a swirling motion to the heavy phase as it is discharged and fillets are fitted into the corners of the mixing chamber in order to preserve this flow pattern.

The pulse line extends above the level of the liquor in the contactor, and an air pocket is maintained between the pulser and the liquid in the pulse line thereby minimizing corrosion. This is analogous to the method used for air-pulsing column contactors which has been described previously. The pulse line can be brought through any biological shielding which may surround the contactor so that only secondary shielding is required around the pulsing unit itself: thus maintenance can be carried out easily.

During operation, light and heavy phases flow by gravity into the mixing chamber and the interface is maintained automatically at the tip of the ejector induction pipe. However, this is only possible provided that the pumping rate of the ejector is greater than the heavy phase flowrate. During the compressive stroke of the pulser, the heavy phase is drawn into the ejector through the induction pipe and discharged into the light phase in the form of small droplets. A certain fraction of the mixed phases passes forward into the settling chamber whilst the remainder settles out in the mixing chamber and is recycled. By this means, the heavy phase is transferred, in the form of a dispersion, from the mixing to the settling chamber and thence to the succeeding mixer whilst the light phase flows through the unit by gravity. If, for any reason, the interface falls below the induction pipe, the ejector will merely recirculate the light phase until the interface has risen to its normal position, as in the K.A.P.L. contactor.[1]

The pulsed mixer-settler possesses many advantages over the conventional type of contactor employing a mechanical impeller, particularly with regard to ease of construction and maintenance. Furthermore, a number of mixer-settlers can be operated from a single pulsing unit, by connecting the ejectors to a common manifold.

Contactor Design

The calculation of the diameter and height of a column type contactor involves a knowledge of the flooding rate and the H.T.U. respectively for the system in question. The calculation of these is summarized below, but for a full treatment, the reader is referred to the original publications.

Diameter—In the case of conventional packed columns,

the dispersed phase hold-up can be related to the superficial phase flowrates by the equation:[3]

$$\frac{V_d}{x} + \frac{V_c}{1-x} = \varepsilon \overline{V}_o (1-x) \qquad (7)$$

where V_o is the "characteristic velocity," identified as the mean relative velocity of the droplets when $V_c=O$ and $V_d \rightarrow O$. Equation (7) is also valid up to the flooding point for spray[14] and for mechanical contactors such as rotary annular,[8] rotary disc[4] and pulsed plate columns,[12] as in these cases, droplet coalescence is reduced to a minimum and the droplet size distribution and hence $\overline{V}_o$ is a function of the contactor geometry and the energy input only for a given system.

If one of the phase flowrates is fixed, an increase in the other flowrate will result in an increased hold-up until the flooding point is reached. Assuming that flooding occurs when V_d or V_c reaches a maximum value (i.e., when dV_d/dx or $dV_c/dx=O$), the value of x corresponding to the maximum flowrates also represents the limiting hold-up at flooding, although mathematically this condition is not inherent in equation (7).

Carrying out the above differentiations, the following equations are obtained relating the phase flowrates at flooding to the limiting hold-up, x_f, and the characteristic velocity $\overline{V}_o$:

$$V_d = 2\overline{V}_o x_f^2 (1-x_f) \qquad (8)$$

$$V_c = \overline{V}_o (1-x_f)^2 (1-2x_f) \qquad (9)$$

eliminating $\overline{V}_o$ between equations (8) and (9)

$$x_f = \frac{(L^2 + 8L)^{\frac{1}{2}} - 3L}{4(1-L)} \text{ where } L = V_d/V_c \qquad (10)$$

A graphical solution of equation (10) has been given elsewhere.[6] Thus if $\overline{V}_o$ is known for a given contactor and system, x_f can be calculated from a knowledge of the flowratio using equation (10) and equations (8) or (9) can then be used to calculate V_d or V_c, and hence the column diameter. In practice, the actual diameter should be larger than the calculated value so that the contactor normally runs at 50% of the flooding rate.

The following equations can be used to calculate $\overline{V}_o$ for various systems and contactor geometries.

(i) Rotary Annular Contactor.[8]

$$\left(\frac{\overline{V}_o \mu_c}{\gamma}\right) = 0.028 \left(\frac{\Delta\rho}{\rho_c}\right)^{1.50} \left(\frac{d_R^2 N \rho_c}{\mu_c}\right)^{-0.18} \left(\frac{g}{d_R N^2}\right)^{1.10} \left(\frac{d_c}{d_R}\right)^{1.20} \qquad (11)$$

This equation has been derived for column diameters of 2 in.-6 in. and for values of the group (d_c/d_R) between 1.2 and 2.0.

(ii) Rotary Disc Contactor.[4]

$$\left(\frac{\overline{V}_o \mu_c}{\gamma}\right) = 0.068 \left(\frac{\Delta\rho}{\rho_c}\right)^{0.82} \left(\frac{d_p^2 N \rho_c}{\mu_c}\right)^{-0.18} \times \left(\frac{g}{d_p N^2}\right)^{1.0} \left(\frac{d_c}{d_p}\right)^{0.14} \left(\frac{d_c}{d_i}\right)^{-1.50} \left(\frac{d_c}{h}\right)^{-0.89} \qquad (12)$$

Equation (12) has been derived for a 3 in. diameter column and for values of (d_c/d_p) between 1.5 and 3.0; (d_c/d_i) between 1.3 and 1.5 and (d_c/h) between 1.5 and 6.0.

(iii) Pulsed Plate Contactor.[12]

$$\left(\frac{\overline{V}_o \mu_c}{\gamma}\right) = 24.4 \left(\frac{\psi \mu_c^5 g_c}{\rho_c^2 \gamma^4}\right)^{-0.23} \left(\frac{\Delta\rho}{\rho_c}\right)^{0.80} \left(\frac{\mu_c^4 g}{\rho_c \gamma^3}\right)^{0.70} \left(\frac{\mu_d}{\mu_c}\right)^{0.31} \qquad (13)$$

Where the work function ψ is the rate of doing work against friction per unit volume of contactor. For sieve plates having 0.125 in. diameter holes and 25% total free area, ψ for a sinusoidal pulse waveform is given by:

$$\psi = \frac{167\ \rho_c}{h_p\ g_c} (fA)^3 \qquad (14)$$

assuming that $\rho_c \simeq \rho_m$. Equations (13) and (14) were derived for column diameters between 3 in. and 12 in. and over this range, $\overline{V}_o$ was found to be independent of diameter. The frequency and amplitude (total) of the pulse varied between 2 and 8 cycles/sec. and 0.25 in. and 1.1 in., respectively, whilst h_p was 2 in.

The shape of the pulse waveform is important and the use of saw-tooth or semi-square waveforms results in smaller diameter droplets which in turn lower the flooding rate of the contactor whilst enhancing the extraction efficiency.[12] Any advantages which might accrue from the increased efficiency are, however, offset by the more intricate design of the pulsing unit and, for practical purposes, it is recommended that a sinusoidal waveform be used. When a reciprocatory air-motor is used to drive the pulsing unit, the waveform deviates somewhat from that of a sine wave, and it is advisable to confirm $\overline{V}_o$ experimentally by carrying out a limited number of flooding measurements in a small-scale contactor. Values of x_f can be calculated from equation (10) using the experimental values of V_d and V_c at the flood-point. The values of x_f so obtained are then substituted into equation (8) and plotted in the form V_d versus $x_f^2(1-x_f)$. The points should lie on a straight line of slope $2\overline{V}_o$ which can be extrapolated through the origin.

Equations (7)-(13) are only valid for solute free systems or when solute transfer is taking place from the aqueous to the solvent phase. When transfer takes place in the reverse direction, droplet coalescence becomes marked and the flooding-rate for rotary and pulsed type contactors is increased by 200-300%. In such cases therefore, the value of $\overline{V}_o$ should be calculated on a solute-free basis, and then an arbitrary correction applied on the assumption that solute transfer will increase the flooding rate by a factor of 3.

Height—Mass transfer data is frequently interpreted for column type contactors in terms of the Height of a Transfer Unit, the over-all values of which are defined as follows for dilute solutions:

$$(H.T.U.)_{oc} = \frac{V_c}{K_c a} \qquad (15)$$

based on the continuous phase, and

$$(H.T.U.)_{od} = \frac{V_d}{K_d a} \qquad (16)$$

based on the dispersed phase.

If subscripts (1) and (2) represent the continuous and dispersed phases respectively, equation (5) (Part I, July) can be written in the form:

$$(H.T.U.)_{oc} = (H.T.U.)_c + V_c/HV_d\ (H.T.U.)_d \qquad (17)$$

Unlike the diameter, the height of a contactor required for a given duty cannot be calculated from first principles as the mechanism of mass transfer is not as yet fully understood. In practice, therefore, a limited number of runs must be carried out using the actual system and the appropriate direction of transfer in a small scale contactor. On plotting the data in the form (H.T.U.) versus (V_c/HV_d), a straight line results and the intercept, corresponding to $(H.T.U.)_c$ is usually small and can be considered constant for the contactor and system in question. The slope is equivalent to $(H.T.U.)_d$ and it is this parameter which is correlated in terms of the relevant variables. When the experimental values of (H.T.U.) are inserted in equations (18) and (19), the appropriate constants, C, can be evaluated and the equations used in conjunction with equation (17) to predict the effect of variations in contactor geometry and energy input upon the over-all H.T.U.

The following equations have been used to correlate $(H.T.U.)_d$:

(i) Rotary Annular Contactor.[8]

$$\frac{(H.T.U.)_d}{d_c} = C \left(\frac{d_R N^2}{g}\right)^{-0.74} \left(\frac{d_c}{d_R}\right)^{1.57} \qquad (18)$$

When the required column diameter has been calculated from equation (11), the corresponding value of $(H.T.U.)_d$ and hence $(H.T.U.)_{oc}$ can be calculated from equation (18). For purposes of scale-up, $d_r^{0.50}N$ is assumed to be constant so that, from equations (11) and (18), $(H.T.U.)_d \propto d_c^{1.05}\ R^{1.55}$ and $\bar{V}_o \propto d_c^{-0.25}\ R^{1.15}$ where $R = d_c/d_R$.

(ii) Rotary Disc Contactor.[4]

$$\frac{(H.T.U.)_d}{d_c} = C\left(\frac{d_p N^2}{g}\right)^{-1.0}\left(\frac{d_c}{d_p}\right)^{1.9}\left(\frac{d_c}{d_i}\right)^{-0.63} e^{-0.57 d_c/h} \qquad (19)$$

Equations (12) and (19) have been used to correlate data obtained with a 3 in. diameter column and they should not therefore be used for columns of very much larger diameter until more information is available. Recommended ratios[4,6] are $(d_c/d_i)=1.3-1.6$ and $(d_c/d_p)=1.6-2.2$ whilst the disc spacing can be obtained from the relation $(d_c/h) \propto d_c^{1}$ ($h=6$ in. for a 24 in. diameter column).

(iii) Pulsed Plate Contactor.[12]

Correlations of $(H.T.U.)_d$ in terms of contactor geometry and pulse waveform are not yet complete, but it is probable that variations in $(H.T.U.)_d$ with pulse characteristics can be correlated in terms of ψ. For design purposes, it is recommended that the sieve plate specification given earlier be used and that $h_p=2$ in. for columns between 3 and 12 in. diameter. The pulse frequency should lie between 2 and 4 cycles/second and the total column amplitude between 0.25 and 0.75 in.

Thanks are due to Dr. H. R. C. Pratt for discussions during the preparation of these articles.

Nomenclature

A	Pulse amplitude (total excursion): ft.
a	Interfacial area per unit volume of contactor: $ft.^2/ft.^3$
C_1C_2	Concentration of diffusing component in phases (1) and (2): $lb./ft.^3$
$C_{1i}C_{2i}$	Concentration of diffusing component at the interface in phases (1) and (2): $lb./ft.^3$
C_1^*	Concentration of diffusing component in phase (1) in equilibrium with concentration C_2 in phase (2): $lb./ft.^3$
C_2^*	Concentration of diffusing component in phase (2) in equilibrium with concentration C_1 in phase (1): $lb./ft.^3$
d	Diameter: ft. Subscript R refers to rotor, c to column, p to disc and i to inside of stator baffle.
f	Pulse frequency: cycles/hr.
g	Acceleration due to gravity: $ft./hr.^2$
g_c	Gravitational conversion factor: 4.17×10^8 lb. (mass) ft./lb. (force) $hr.^2$
H	Partition coefficient for system.
h	Distance between rotor discs: ft. With subscript p refers to distance between sieve plates.
K_1K_2	Over-all mass transfer coefficient based on concentrations in phases (1) and (2): ft./hr.
K_cK_d	Over-all mass transfer coefficient based on concentrations in the continuous and dispersed phases: ft./hr.
k_1k_2	Film mass transfer coefficient for phases (1) and (2): ft./hr.
N	Rotor speed: revs./hr.
N_A	Rate of transfer of solute A: lb./hr.
S	Interfacial area: $ft.^2$
V	Superficial velocity: ft./hr. Subscript c refers to continuous phase and d to dispersed phase.
$\bar{V}_o$	Characteristic droplet velocity, i.e., mean droplet velocity when $V_c=0$ and $V_d \rightarrow 0$: ft./hr.
x	Fractional hold-up of dispersed phase. Subscript f refers to value at the flood-point.
θ	Time: hrs.
$\mu_c\ \mu_d$	Viscosity: lb./ft. hr. Subscript c refers to continuous phase and d to dispersed phase.
γ	Interfacial tension: $lb./hr.^2$
ρ	Density: $lb./ft.^3$ Subscript c refers to continuous phase and m to phase dispersion.
$\triangle\rho$	Density difference of phases: $lb./ft.^3$
ψ	Work function, i.e., input per unit time per unit volume of contactor: ft. lb. (force)/hr. $ft.^3$
ϵ	Fractional voidage of packing—unity for rotary and pulsed contactors.

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Les Contacteurs mécaniques à grand Rendement pour les Opérations Liquide-Liquide

La partie 2 décrit un nombre de contacteurs mécaniques d'essai qui ont été employés à l'Institut de Recherches de l'Energie Atomique, à Harwell, pour obtenir des données pour la construction d'appareillage d'extraction de liquide-liquide radio-actif. On y donne des détails de construction de contacteurs rotatifs à anneau et rotatifs à disque (Type IA), de contacteurs de Type IB pulsés mécaniquement at à l'air employant des colonnes à plaques-tamis, et des mélangeurs-sédimentateurs pulsés de Type IIB.

Pour la projection de ces contacteurs, le calcul du diamètre et de la hauteur d'un type à colonne nécessite une connaissance du taux de noyage et de la "H.T.U." (hauteur du groupe de transfer). Les calculs de ces données y sont résumés et les équations appropriées pour les contacteurs rotatifs-annulaires, rotatifs à disque et à plaque pulsée y sont données. La nomenclature employée dans les équations est définie.

Hochwirksame mechanische Kontakteinrichtungen für flüssig-flüssig Extraktionsprozesse

Teil 2 beschreibt eine Anzahl von zu Versuchszwecken gebauten mechanischen Kontaktoren, die im "Atomic Energy Research Establishment" in Harwell in Benutzung genommen waren, um Daten für den Entwurf von radio-aktiven flüssig-flüssig Extraktionsanlagen zu bekommen. Es werden Konstruktionsdetails von rotierenden Ring- und rotierenden Scheibenkontaktoren (Type IA) gebracht, ferner von mechanisch pulsierenden und pneumatisch pulsierenden Kontaktoren, Type IB, die mit Säulen von Siebplatten arbeiten, und von pulsierenden Misch- und Absetzmaschinen der Type IIB.

Wenn man solche Kontaktoren entwirft, dann erfordert die Berechnung von Durchmesser und Höhe der Säulentypen Kenntnis des Ueberflutungsgrades, beziehungsweise der "H.T.U." (Höhe einer "Uebertragungseinheit"). Berechnungen dieser Werte werden zusammenfassend gebracht, und die erforderlichen Gleichungen für rotierende Ring-, rotierende Scheiben- und pulsierende Plattenkontaktoren aufgestellt. Die Bezeichnungen, die in den Gleichungen verwendet werden, werden definiert.

Contactores de alta Eficienia para Procesos de Extracción del tipo Líquido-Líquido

En la Parte 2 se describen ciertos contactores mecánicos experimentales que se han venido usando en el Establecimiento de Investigación de Energía Nuclear en Harwell, para conseguir datos para el diseño de equipo de extracción de líquido-líquido radioactivo. También se ofrecen datos de construcción de contactores de anular rotativo y de disco rotativo (Tipo IA), de contactores de pulsación mecánica y de pulsación por aire Tipo IB empleando columnas de plancha de tamiz y mezcladores-asentadores pulsados del Tipo IIB.

Al diseñar estos contactores los cálculos sobre el diámetro y altura de un tipo de columna implica el conocimiento de la razón de anegamiento y de la H.T.U. (Altura de una Unidad de Transferencia), respectivamente. Los cálculos para estos quedan resumidos y las ecuaciones pertinentes para los contactores rotativos anulares, disco rotativo y plancha pulsada se ofrecen también. La nomenclatura empleada en las ecuaciones es definida, igualmente.

World News

Visitors from Spain (see this page) and members of the John Thompson Group examining the model of the Dounreay fast reactor.

L. to R.: Mr. W. R. Edwards, Managing Director, John Thompson Water Tube Boilers; Mr. P. K. Richards, Assistant to the head of John Thompson Atomic Energy Department; Mr. E. W. Thompson, Chairman and Managing Director, John Thompson Limited; His Excellency Don Juan Antonio Suanzes Fernandez, President, Institute Nacionale de Industria, with Mr. J. H. N. Thompson, Joint Managing Director, John Thompson Limited, in the background; Senor Don Jose Maria De Gaztelu, Chief Electrical Engineer; Senor Don Jose Sirvent Dargent, Director, Institute Nacionale; Senor Don Ricardo Gimenez-Arneu, Economic Councillor, Spanish Embassy, London; Mr. J. W. Kendall, Head of John Thompson Atomic Energy Department; and, with his back towards the camera, Senor Don Manuel Salis Martinez.

UNITED KINGDOM

Scotland is to have an atomic power station, the South of Scotland Electricity Board has announced, after consultation with the A.E.A. The station, of the graphite-moderated, gas-cooled type, will have two reactors, and a planned capacity of 250-300 MW. Although the site has not yet been announced, the load centre dictates a location to the west of the Board's area, and several sites along the Ayrshire coast are being examined. It is expected that the capital cost will be around £35 million and the station will supply about one-fourth of the total load in the south of Scotland area, with an estimated annual saving in coal of about 1 million tons. The possibilities of pumped hydro storage for off-peak loading are being investigated.

Formal approval by the Minister of Fuel and Power has now been given to the nuclear power stations at Bradwell, Essex, and Berkeley in Gloucestershire, the first two of the twelve 200 MW stations outlined in the White Paper of February last year. Although proposals from the four manufacturing groups are not due until October, preliminary work at both sites is proceeding, to eliminate delays. Construction is expected to start in the New Year.

Uniform nomenclature for equipment used in nuclear research and engineering was the subject of a question in the House, where the desirability of such uniformity was stressed by Mr. Neave. Mr. R. A. Butler (Lord Privy Seal) pointed out that the B.S.I. and A.E.A. were preparing a glossary of terms and that the O.E.E.C. also had a programme for establishing a uniform nomenclature amongst its member countries.

The U.K.A.E.A. Weapons Group has placed instructions with A.E.I.-John Thompson Nuclear Energy Co. Ltd. to commence design and construction of a swimming-pool reactor at the Aldermaston establishment. The reactor will be similar to MERLIN, a brief description of which was given in the April issue of *Nuclear Engineering*, except that invested reactivity will be 8%. The maximum power rating will be 5 MW as proposed for MERLIN. Discussions between the Authority and the company have been under way for nearly nine months and it is understood that preliminary plans are already complete. Work is now proceeding on the foundations of the A.E.I. reactor at their research laboratories also located at Aldermaston.

Delegates from Spain representing the Spanish Government paid a visit to Britain in mid-July remaining as the guests of H.M. Government, to study the development of nuclear energy in this country. Under the auspices of the Board of Trade, the party, headed by H.E. Senor Don Juan Antonio Suanzes Fernandez, president of the Institute Nacionale de Industria, and Senor Don Jose Maria de Gaztelu, chief electrical engineer, visited a number of establishments of the Atomic Energy Authority and several manufacturing companies interested in the nuclear field. A.E.A. establishments included Calder Hall, Windscale, Harwell, Risley and Aldermaston, and the commercial firms included an extensive tour of the Wolverhampton factories of the John Thompson Group (see illustration, this page) where they were shown fabrication of stainless-steel components for the Dounreay fast breeder reactor. Other companies visited were BTH (Rugby and Willesden), English Electric, C. A. Parsons, Fraser and Chalmers, John Summers and Metropolitan-Vickers Ltd.

Civil engineering work at Chapel Cross is several weeks ahead of schedule, according to latest available reports. Chapel Cross, near Annan, Dumfriesshire will be, of course, practically a duplicate of Calder Hall.

INTERNATIONAL

The Paris Conference of O.E.E.C. has set up a "steering committee" to prepare a draft statute for a European Nuclear Energy Agency, including joint industrial enterprises. Britain has indicated her willingness, according to a Reuter report, to assist European atomic development with her nine years' experience and "know-how" of the nuclear industry, as well as taking an active part in one of the proposed joint undertakings, a chemical separation plant. The other working groups cover an isotope separation plant and a heavy water plant. Two study groups are being formed on experimental and prototype reactors, it being felt that matters were not far enough advanced for working groups. The steering committee is also to examine the liaison and links with the proposed International Atomic Agency and with Euratom, and to investigate methods of achieving standardization in the atomic industry.

According to *The Times* Britain has stated that based on her experience with the New Zealand scheme, she does not consider a heavy water plant to be practicable or economic. Similar views were expressed regarding the isotope plant, nor will she be prepared to play a part in the chemical separation factory. She will, however, play a part in the steering committee even if she does not take part in the maintenance of any of the plants nor, indeed, in their construction of any except the chemical separation plant.

EUROPE

A report of the O.E.E.C.'s Commission for Energy says that Western Europe's energy consumption is rising so rapidly that from the equivalent of 730 million tons of coal in 1955 it will reach the equivalent of 1,200 million tons in 1975, by which time the deficiency in production will necessitate importing coal and oil to the value of $5,000 million. Nuclear energy could only provide about 8% of total requirements by 1975, although its contribution would be increasingly significant after this. Its development was vital to the

future prosperity of Europe and a heavy expenditure of money and technical effort was necessary to this end.

FRANCE

Increases in power requirements in France have been estimated as greater than that normally quoted in industrial communities. Electricité de France is planning an output of 60 MW from atomic energy by the end of 1959, followed by a second installation of a considerably greater power by the middle of 1961. In a statement recently the director-general of research at E.D.F. implied that atomic energy was regarded as the major source of power for the next generation.

Uranium production. Reports indicate that the production of uranium, which is already considerable, can be quadrupled in three years. Taking into account the thorium deposits in Madagascar, France is thus in a comfortable position regarding raw materials and it is possible that once regular production has become established she will be not only self-sufficient but in a position to éxport uranium and thorium metal.

The isotope school which up to the present time has been situated at Chatillon and the University is to move to Saclay where a laboratory and study rooms have been completed.

BELGIUM

Under a new agreement the U.S. has undertaken to widen the scope of interchange of secret information on peaceful applications of nuclear energy. This extends an agreement signed in July, 1955. Purchase of uranium ore from Belgium, one of America's major suppliers, is unaffected by the agreement. It is also reported that Belgium is to receive 8 kg of enriched (90%) uranium for use in the high-flux reactor to be located adjacent to the present Mol experimental reactor. Under the agreement Belgium could transfer its rights to an "integrated" group of nations, i.e., Euratom.

Man behind Euratom. M. Paul-Henri Spaak, Belgian Foreign Minister, is visiting the Belgian Congo this month, Reuter reports. He is visiting the Shinkolobwe workings of the Union Minere du Haut Kataranga, the world's largest uranium mine. The company is this year celebrating its 50th year of establishment.

Disposal of radioactive wastes was the theme of a conference held in Brussels at the end of July by the European Atomic Energy Society. Problems discussed included disposal of waste waters, disposal of waste solids, problems related to radioactivity elimination and measurements; problems of disposal from a public health standpoint.

HOLLAND

An agreement with the U.S., superseding one concluded a year ago, provides for a 10-year comprehensive exchange of information, both secret and non-secret, on peaceful uses of atomic energy including industrial applications and nuclear power development.

A six-day conference on nuclear physics held in Amsterdam early in July was attended by more than 500 physicists representing 26 countries.

Left: A cobalt gun in the Soviet Pavilion at the Atoms for Peace exhibition held in conjunction with the Swedish Industries Fair.

Right: A mass spectrometer also in the Soviet Pavilion.

BULGARIA

Atomic energy research. Work has begun on an atomic energy research station near Sofia, a Bulgarian news agency has reported. Much of the equipment and technical information will be supplied by the Soviet Union and technical personnel from the U.S.S.R. will help in the building and the initial commissioning.

U.S.S.R.

Tass reports that an experimental refinery utilizing nuclear energy is being constructed at the Azerbaijan Oil Refining Research Institute at Baku. It is claimed that irradiation enables benzine production to be carried out at room temperatures.

Russia has proposed an all-Europe conference to consider the formation of an organization for the peaceful use of the atom, according to a Reuter report. The proposal declared that Euratom was "subordinated to the military strategic bloc to which its members belong," and, declared that its effect would be to widen the split between East and West Germany and create a menace to the peace of Europe. The proposed all-European co-operation would not exclude bilateral agreements, providing they were on a basis of equality. The U.S. could also participate.

Moscow reports that an exhibition devoted to the peaceful uses of atomic energy has been held in Leningrad.

CHINA

Uranium deposits of high grade have been reported on Hainan island which is situated off the south coast of Communist China. The island is already mining iron and tungsten ores and preliminary reports on the uranium deposits indicate that concentration is considerably greater than in the deposits at Sinkiang. It is suggested that mining operations on the uranium ore have already begun.

PAKISTAN

Search for radioactive minerals will commence in September by three groups of Pakistani scientists, under the supervision of the Pakistan Atomic Energy Commission which has also arranged that engineers of the ground water development organization will combine a search for radioactive minerals with their work of boring hundreds of tube wells.

Pakistan is negotiating with the United States, according to Reuter, for a reactor to be installed under the auspices of both nations.

INDIA

Heavy water manufacture may one day be economically carried out in India from bitterns, a waste by-product of salt manufacture, according to a report from Bangalore. The suggestion has been made by an American chemical engineer, Mr. G. T. Austin, working at the Indian Institute of Science, to which he was assigned under an exchange scheme sponsored by the University of Winsconsin. Mr. Austin attributes the "lead" to Dr. Weingartner, director of the chemistry department at the Indian Institute of Science.

A model of the first nuclear reactor for the Far East, which is being built by Atomics International, a division of North American Aviation, Inc., for the Atomic Energy Research Institute of Japan, is inspected by Susumu Suguri (left), of the Japanese Ministry of International Trade and Industry, and Kiyoaki Taketani, of Tokyo University, who will use the reactor in their studies. The reactor is practically identical with that supplied to the Armour Foundation (see p. 198).

INDIA

Further information is now forthcoming about the Trombay reactor briefly mentioned in previous issues. The reactor known as the C.I.R. (Canada-India Reactor) is of the N.R.X. type like that at Chalk River, and is being supplied by the Atomic Energy of Canada Ltd., manufacturing being carried out by the Shawinigan Engineering Co. Ltd. of Montreal. Indian scientists and technologists are being seconded to Canada to obtain operating experience in the operation of the Chalk River reactor and to take part in the design work. Indian contractors and labour will carry out construction work at the site; Canadian technicians will supervise the erection. The C.I.R. reactor is said to have a number of improvements and more extensive facilities for research work than the original Chalk River reactor.

JAPAN

The 100 MW nuclear power station mentioned in our July issue (page 170) as being a possibility for Japan has not so far crystallized. In place of a 100 MW station, it was later reported that the Japanese Atomic Energy Commission had revised their ideas and were considering a smaller-scale unit of 10 MW. It was reported towards the end of June that an investigation team would probably visit Britain shortly but later reports state that the visit will be postponed until the Autumn when Calder Hall would be in full operation. Sir Christopher Hinton is said to have suggested a 60 MW unit.

SOUTHERN RHODESIA

Talks on uranium have been taking place between the Federal and Territorial governments and two members of the British A.E.A., during which general matters relating to the location, mining and use of radioactive mineral deposits have been discussed, according to Reuter. There is already an office of the A.E.A. established in Salisbury.

U.S.A.

Nuclear energy has been the cause of more than one clash in U.S. politics during the last month. Following an agreement between Britain and the U.S. authorizing the exchange of information regarding the use of nuclear energy in land and marine propulsion units, a Bill was introduced into Congress to prevent this exchange, on the grounds that such information was of a military nature. According to *The Times* this attitude is partly due to Britain's supposed lack of adequate security. At the moment, the agreement is actually in existence.

On July 12, according to Reuter, the Senate authorized the U.S. Government to spend $400 million on reactor schemes. Republicans voting against the Bill said that it was not only not needed but might actually retard the efforts of private industry in the atomic field by discouraging private capital. On July 24, however, the House of Representatives by a very narrow margin, sent the Bill back to committee, so that it cannot pass before Congress adjourns.

Three years delay may be caused on the Monroe (Michigan) plant planned for 1960 by Atomic Power Associates, headed by Detroit Edison, due to recommendations by an A.E.C. advisory committee that investigations should be carried out on a small-scale prototype in place of the 100 MW unit at present scheduled.

"Nautilus," the world's first nuclear-powered submarine has cruised more than 50,000 miles without refuelling.

Another nuclear submarine, the "Sea-Dragon," is building at Portsmouth, New Hampshire.

A Conference Committee of the Senate and the House of Representatives has agreed on a Bill authorizing the U.S. to build the world's first nuclear-propelled merchant ship. Reuter reports that the estimated cost is some $40 million.

Medical research centre at Brookhaven L.I. is to contain the first reactor designed specifically for medical research and therapy.

A summer "atomic college" has been instituted at the Argonne National Laboratory where each summer 60 engineering professors will take an eight-week course. The scheme is jointly sponsored by the American Society for Engineering Education, the National Science Foundation, the A.E.C. and North-Western University.

Golden Crown Mining Company is starting production at their Orphan uranium property at Grand Canyon, Arizona. Drilling has shown there to be several hundred thousand tons of pitchblende uranium ore with an average grade of at least 0.45% uranium oxide.

CANADA

Five hundred million dollars, it is reported, are to be spent by the United Kingdom on Canadian uranium ore concentrates, between 1962 and 1967, under an agreement recently concluded between the A.E.A. and Eldorado Mining and Refining Ltd., a Crown corporation. This is said to be about one-half of the amount sold to the United States. Canada is prepared, according to the Quebec Press, to supply uranium for research purposes to other countries. She would, however, insist on a guarantee that the material would be used for peaceful purposes only.

Information on nuclear propulsion for aircraft, vehicles and naval vessels has been offered to Canada by the U.S. under a new agreement, according to a Reuter report. Hitherto exchange of information has been entirely on peaceful applications, military information being specifically prohibited under the existing agreement which the U.S. has now proposed should be modified.

Two uranium mines, the Quirke and the Nordic, in Ontario's Blind River area, are each expected to be producing 3,000 tons a day of uranium ores before the end of the year, the Quirke mine being scheduled to commence production in September.

Both mines are owned by Algon Uranium Mines, Ltd., which has recently been awarded a contract for more than 200 million dollars—the largest ever awarded in Canada.

Estimates for the expenditure in 1956-1957 year by the Atomic Energy of Canada Ltd., total over $22 million. Included in this figure is $595,000 to be spent by the Federal Government for research on large nuclear power plants. Although nuclear power is not required urgently at the present time the Government intends to ensure that Canada is not left behind in the development of nuclear generating stations.

More than 300 reports on nuclear energy published by Atomic Energy of Canada Ltd. from April, 1952, to May, 1956, are summarized in a new list recently issued. Copies of the list and the various reports may be obtained from the Scientific Document Distribution Office of A.E.C.L. at Chalk River, Ontario.

COLOMBIA

Radioactive mineral production is being anticipated by the Government of Colombia by the formation of the Instituto Colombiano de Asuntos Nucleares.

AUSTRALIA

Uranium minefields at Rum Jungle are now in full production except for normal mining difficulties.

A 10-year treaty signed with the United States provides for a comprehensive exchange of classified and unclassified information on peaceful applications of nuclear energy, and for American assistance in the development of the Australian nuclear power programme. Australia is also to receive up to 1,100 lb. of U 235 fuel.

More than £A35,000 has recently been paid by the Australian Government to six prospectors for uranium discoveries, Reuter reports. These include the rich Mary Kathleen deposits in Queensland for which the maximum award was paid. Rum Jungle, in the Northern territory, has so far been the only "strike" which has earned the maximum award.

Twelve research contracts have been awarded to Australian universities with a total value of £38,000 bringing the total research grants to £68,700. Included in the grants to the University of Melbourne is money for the development of refractory materials with possible applications to advanced types of reactors and to the Department of Mining for further studies on uranium ore treatment particularly flotation methods.

Trade Notes

A 2MeV Van de Graaff accelerator has been purchased by Magnolia Petroleum Company of Dallas, Texas.

Simon-Carves Ltd. is to increase its capital to £2 million; shareholders approved the proposal at the A.G.M. on July 9.

Welding of nickel and its alloys is the subject of a new 45-minute film now available on loan from Henry Wiggin and Co. Ltd., Thames House, Millbank, London, S.W.1.

The Solartron Electronic Group Ltd., Thames Ditton, Surrey, is planning to set up a sales and service company in America. A team of sales engineers is already in the U.S. demonstrating equipment, and has established headquarters at Western Instrument Inc., Burbank, Los Angeles.

Efco-Edwards Vacuum Metallurgy Ltd., a new company, just announced, represents a fusion of interests between Edwards High Vacuum Ltd. of Manor Royal, Crawley, Sussex, and the Electric Furnace Co. Ltd. of Queens Road, Weybridge, Surrey, who as specialists in vacuum technique and furnace design, respectively. It is understood that the new company represents a separate entity and that the parent organizations will retain their original independent existence.

Capacity of the Brinsworth, Yorkshire, works of British Oxygen Gases Ltd. is being increased by the addition of a second large liquid oxygen plant to meet increased demands in the area.

Bessbrook Products Ltd. is the name of a new company which has been formed in Northern Ireland by Pye Ltd., Cambridge, in association with Aberdare Electric Co. Ltd. of Dublin, for the manufacture of electrical products. A factory will be erected at Bessbrook, County Armagh.

Winston Electronics Ltd., Shepperton, Middlesex, have had their telephone number changed to Walton-on-Thames 6321.

Aero Research Ltd., Duxford, Cambridge, announce that their telephone number is now Sawston 2121; the Telex number is 10-101.

Ionics Inc. of Cambridge, Mass., has set up a special nuclear department under Dr. J. A. Marinsby, assistant director of research of the parent company, and co-discoverer of the element promethium. Ionics' radiochemical and trace-element analytical service is being transferred to the new department.

Over 200 companies have already applied for stand space at the Chemical and Petroleum Engineering Exhibition which will be held at Olympia from June 8-18, 1958.

Catalogues

Armoured Rotameters.—A 12-page bulletin describing and illustrating the range of Brooks Rotameters for high pressure and temperature fluid flow-rate measurement and control. Brooks Rotameter Company, Lansdale, Pennsylvania, U.S.A.

The Link: No. 1, May.—The first issue of a new quarterly works magazine issued by the Richardsons Westgarth Group. An article outlines the group's interest in nuclear engineering and gives some information on the chief personalities involved. Richardsons, Westgarth and Co. Ltd., Wallsend.

SS News Letter.—The May issue is largely devoted to equipment for non-destructive testing made by Solus-Schall Ltd., and General Radiological Ltd. It is published by Solus-Schall Ltd., 12-18 Clipstone Street, London, W.1.

The Non-Destructive Testing of Engineering Materials.—An informative and well-referenced 32-page booklet published by A. E. Cawkell, electronic engineers, Southall, Middlesex, describing their UCT and SCT ultrasonic units and their applications.

Structural Aluminium.—A 150-page handbook compiled to provide the structural engineer with the basis of a sound approach to design in aluminium. Chapters deal with the various alloys and their characteristics, available forms, design considerations, joining and fabrication, useful formulæ, and tables of properties of Noral products. Northern Aluminium Co. Ltd., Banbury, Oxfordshire.

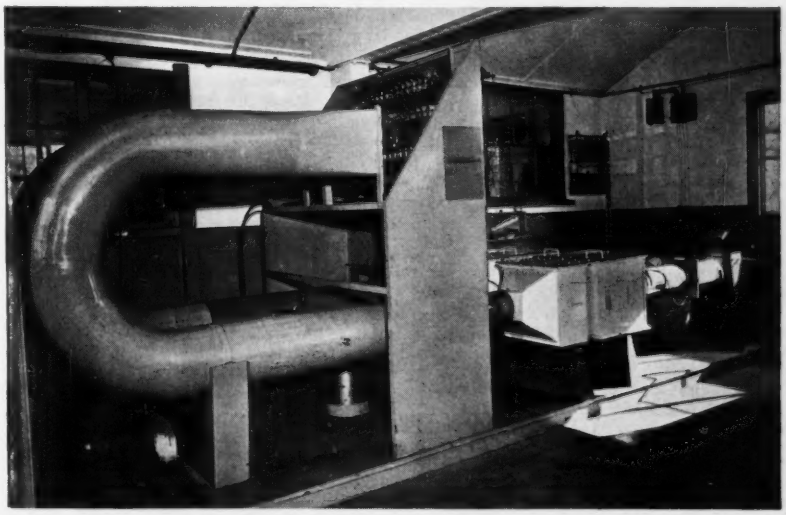
Aero Research Technical Notes.—Bulletin No. 159 is devoted to the first part of an article by Dr. E. Niskanen of the Wood-Technical Laboratory, Helsinki, on glued laminated timber structures. Aero Research Ltd., Duxford, Cambs.

Londex Photo-electric Equipment.—An 8-page catalogue of the equipment made by Londex Ltd., Anerley Works, 207 Anerley Road, London, S.E.20.

Fans, Blowers and Exhausters.—This 40-page booklet, publication No. 2206 is the latest catalogue of Sturtevant equipment. It is excellently illustrated, with tables of performances, dimensions and many photographs of actual installations. Sturtevant Engineering Co., Ltd., Southern House, Cannon Street, London, E.C.4.

Battersea Works: 1856-1956.—An extremely well-produced and illustrated 68-page book commemorating the centenary of the Morgan Crucible Co. Ltd., Battersea Church Road, London, S.W.11. The history of the growth of this company out of a firm of druggist sundriesmen and hardware merchants makes interesting reading.

Tracerlog, June 1956.—This issue contains articles on plastic phosphors and the conversion efficiency of a plastic scintillator. Another article deals with the Tracerlab RLP-6 automatic stepping single-channel pulse height analyser.



Vokes Absolute air filters, of a type supplied to the U.K.A.E.A., being subjected to the methylene blue penetration test. In this test, dye particles are introduced into the air-stream, 90% being below 0.5 microns in size whilst 50% are actually less than 0.05 microns. These box type canisters permit a dye penetration of less than 0.005%.

Mr. H. G. Nelson.

Mr. F. W. Gardner.

Mr. C. Metcalfe.

Mr. G. H. Orgelman.

Personal

Sir George H. Nelson has relinquished the position of managing director in order to devote the whole of his time to the duties of executive chairman of the English Electric Co. Ltd. **Mr. H. G. Nelson**, M.I.C.E., M.I.Mech.E., M.I.E.E., has been appointed managing director.

Mr. G. Craven, D.S.C., a director of English Steel Export Corporation Ltd., has been appointed a director of English Steel Forge and Engineering Corporation Ltd., responsible for commercial matters.

Mr. H. W. G. Hignett has been appointed assistant managing director of Henry Wiggin and Co. Ltd., producers of special high nickel alloys. As a director of the company, Mr. Hignett was previously responsible for technical metallurgical control and development.

Mr. A. H. Giles, formerly of Heat Exchangers Ltd. and Superheater Co. Ltd., has joined Heat Transfer Ltd. as managing director.

Mr. C. Metcalfe has been appointed managing director of E.M.I. Electronics, Ltd., which will take over the research, development and manufacture on Government contracts and commercial electronics on behalf of the E.M.I. Group.

Mr. G. E. Condliffe has relinquished his position of managing director of E.M.I. Research Laboratories Ltd., to take over the post of research and technical consultant to the chairman and the managing director of Electrical and Musical Industries Ltd.

Mr. A. H. Hird, A.C.G.I., B.Sc., M.I.Mech.E., is appointed a special director of Vickers Ltd. and adviser on group commercial engineering sales. He also takes over the chairmanship of A.B.C. Motors Ltd., Cooke, Troughton & Simms Ltd. and Ioco Ltd. He will remain on the board of Vickers-Armstrongs Ltd. as engineering sales director and on the board of Vickers-Armstrongs (Engineers) Ltd. **Mr. E. J. Waddington**, A.C.A., and **Mr. R. P. H. Yapp** relinquish their seats on the boards of Ioco Ltd. and Cooke, Troughton & Simms Ltd., respectively, and Mr. Waddington also the chair of A.B.C. Motors Ltd., though remaining on the board of that company. **Mr. R. Wonfor** and **Mr. J. E. Richardson**, O.B.E., have been appointed to the board of Vickers-Armstrongs (Engineers) Ltd., Mr. Richardson retaining his office of deputy general manager and engineering manager, Barrow Works. **Rear-Admiral Sir Anthony Buzzard**, Bart., C.B., D.S.O., O.B.E., is appointed a special director of Vickers-Armstrongs Ltd. and assistant to the managing director.

Mr. H. West, Assoc.M.C.T., M.I.Mech.E., M.I.M.E.E., has been appointed managing director of A.E.I.-John Thompson Nuclear Energy Co. Ltd. Mr. West was previously chairman of the management committee of the company. He retains his directorship of Metropolitan-Vickers Ltd., and his position as chief electrical engineer. He recently joined the Board of Isotope Developments Ltd. Mr. West will remain at Trafford Park.

Mr. F. W. Gardner, director and general manager of C. A. Parsons and Co. Ltd., retired on June 30 after 44 years with the company. He retains his seat on the board of directors.

Mr. A. N. E. McHaffie has retired from the board of Associated Electrical Industries Ltd.

Dr. J. M. Kay has been appointed to the newly instituted chair of nuclear power at the Imperial College of Science and Technology. Dr. Kay is a consultant in the field of nuclear power and related industries.

Sir Luke Fawcett has been reappointed part-time member of the United Kingdom Atomic Energy Authority until July 31, 1957.

Mr. O. W. Humphreys, director of the General Electric Co. Ltd., in charge of research, has been elected president of the Institute of Physics at the A.G.M. **Dr. B. P. Dudding** was elected a vice-president, **Dr. J. Taylor** honorary treasurer and **Professor F. A. Vick** honorary secretary. **Dr. L. R. G. Treloar** and **Mr. G. W. Warren** were elected to the board. **Sir George Paget Thomson** was elected to honorary fellowship in recognition of his contributions to physics and to physicists.

Mr. C. F. Uwins has been elected president of the Society of British Aircraft Constructors, **Mr. A. F. Burke** vice-president and **Mr. J. J. Parkes** deputy president. **Sir Frederick Handley Page** has been re-elected honorary treasurer.

Mr. Schierbeek, formerly head of the Mines division, has been appointed head of the nuclear energy division established at the Netherlands Economic Affairs Ministry under the Directorate-General for industrialization of power.

Mr. J. S. V. Andrews, formerly works director of the Mersey Cable Works Ltd., part of the Tube Investment Group, has been appointed chief planning engineer of James A. Jobling & Co. Ltd.

Mr. A. C. Ellis, district manager of the Cardiff office of Metropolitan-Vickers Electrical Company since 1952, has returned to the company's Manchester office as district manager.

Mr. G. H. Orgelman, formerly associated with Chance Vought Aircraft Incorp., has joined General Precision Laboratory Incorp. as personnel director. **Mr. D. S. Kellogg** has been appointed chief engineer of the Avionic Engineering Division of G.P.L., **Mr. W. H. Heath** assistant engineer, **Dr. G. R. Gamertsfelder** director of research and **Mr. Otto J. Kolb** chief product engineer.

Mr. J. M. Furnival, M.B.E., has retired from his position as general manager of Marconi Instruments Ltd., continuing however with the company in a consultative capacity. **Mr. R. E. Burnett**, M.A. (Oxon.), A.M.I.E.E., A.Inst.P., formerly the company's deputy general manager, has succeeded him.

OBITUARY

It is with deep regret that we have to announce the death of **Dr. Cecil Eddy** who supervised the safety arrangements for the atomic test in the Monte Bello Islands.

We also regret to announce the death of **Mr. Harold Edward Midgley**, a director of the Brush Group.

FORTHCOMING MEETINGS

British Nuclear Energy Conference

November 22-23.—Symposium on Calder Works Nuclear Power Plant. At the Institution of Civil Engineers, Great George Street, London, S.W.1.

November 22.—"British Nuclear Power Programme" by Sir Christopher Hinton; "The Design Study" by R. V. Moore and B. L. Goodlet; "The Calder Works Plant" by R. V. Moore—at 10 a.m. "Experimental Heat Transfer Work" by P. Fortescue and W. B. Hall; "Experimental Physics" by P. Mummery; "Shielding Design" by W. Bonsall and C. Horton; "Basic Design of Reactor" by G. Packman and B. Cutts; "Early Metallurgical Problems" by L. M. Wyatt and R. A. U. Huddle; "Metallurgical Developments for Calder Works" by L. Grainger and A. B. McIntosh—at 2 p.m.

November 23.—"Design and Construction of Reactor Vessel" by G. Brown; M. Noone and R. F. Bishop; "Uranium Fuel Handling" by K. Dent and G. W. Grossmith; "Design of Important Plant Items" by A. T. Bowden and G. H. Martin; "Steam Cycle Analysis" by W. R. Wootton; "Design and Construction of Heat Exchangers" by H. Morris and W. R. Wootton—at 10 a.m. "Equipment for Control of the Reactor" by J. H. Bowen and S. A. Ghalib; "Detection of Faulty Fuel Elements" by E. Long, J. M. Laithwaite and K. W. Cunningham; "Reactor Control and Instrumentation" by R. J. Cox and K. R. Sandiford; "System Control and Protection" by J. H. Bowen and E. Anderson—at 2 p.m. "Future Developments of Gas-cooled Reactors" by R. V. Moore—at 5.30 p.m.

Institute of Physics

September 26-27. — Symposium on Magnetic Resonance. At the University College of North Wales, Bangor. Lectures include: "Free Atom Resonance" by B. Bleaney; "Spin Echo Techniques" by J. G. Powles; "Magnets" by R. E. Richards; "Nuclear Magnetic Resonance Work, and other Research at Bangor" by E. R. Andrew.

Technical Papers and Publications

B.N.E.C.

Papers presented at a meeting organized by The Institute of Physics, 47 Belgrave Square, London, S.W.1, and held at the Institution of Electrical Engineers from July 3-6. Extracts from Sir John Cockcroft's opening address on "Scientific Problems in the Development of Nuclear Power" will be found on pages 193-194.

The Physics of Advanced Reactors *by Dr. J. R. Dietrich (Argonne National Laboratory, U.S.A.).*

This discussion is an attempt to characterize the various promising types of solid fuel power reactors in terms of the neutron-physics characteristics of their moderators, coolants, and fuel cycles.

The neutron-physics design objectives which have the greatest effect on power cost are:

(i) use of a fertile isotope (uranium-238 or thorium-232) as a major source of energy; (ii) internal conversion ratio high enough to allow long fuel element life; (iii) safety characteristics favourable enough to avoid remote location and high containment cost.

These objectives are not restrictive enough to define the "best" reactor type, but they are the major factors in determining the composition and geometric arrangement of specific reactor designs once the type has been chosen.

The thermal reactors which are at present being designed or constructed utilize uranium-235 as the initial fissile isotope, and there is a strong incentive to utilize ratios of fissile to fertile material which depart as little as possible from the "natural" value. With this additional design restriction, the lattice characteristics appropriate to the various moderator-coolant combinations are still more sharply defined. Examples are drawn from the current group of reactor designs to illustrate these characteristics. The possible consequences of a greater latitude in the choice of fissile-fertile ratio are discussed, and the relative characteristics of the possible fuel cycles are considered.

The characteristics of fast reactors fit into a quite different pattern. The possible conversion ratio is high on either fuel cycle, and the reactivity changes associated with fuel burn-up are relatively low simply because of the very large fissile-material content of the reactor. The requirement that the average neutron energy be kept high is a rather restrictive one. It appears now that the range of variation in fast reactor design will be less than that in the thermal reactor field. The characteristics of typical fast reactors are presented, their special problems are discussed, and some recent experimental results are quoted.

Experimental Reactor Physics *by P. W. Mummery (Atomic Energy Research Establishment, Harwell).*

The successful design, construction and operation of nuclear reactors requires detailed information concerning the interaction of various nuclear radiations with matter. In principle this can be obtained from a knowledge of fundamental atomic and nuclear properties combined with mathematical treatments. In practice a considerable number of integral measurements are required. These experiments measure combinations of various fundamental atomic and nuclear properties and the prediction of the mathematical treatments.

The detailed information required is outlined and various integral measurements are discussed together with their correlation with fundamental data and with various mathematical models. Consideration is given to the use of sub-critical, and low power and high power critical reactor assemblies in this field.

The Zero Energy Fast Breeder Reactor, Zephyr *by Dr. L. R. Shepherd (Atomic Energy Research Establishment, Harwell).*

ZEPHYR is a small low-power fast reactor with a plutonium core surrounded by an envelope of natural uranium. No cooling is required since the maximum operating power is about 2 W. This reactor first diverged in February, 1954, and has been used to make a detailed study of the neutron physics of fast reactors. Of the many aspects investigated, particular attention has been given to a determination of the breeding characteristics of the system and the measurement of the nuclear parameters required for a theoretical interpretation of fast reactors.

Recent Developments in Nuclear Theory *by Prof. R. E. Peierls (University of Birmingham).*

This discourse refers to the following topics: The shell model of nuclear structure and its relation to our knowledge of nuclear forces; collective motion and surface rotations; highly excited states and the relation between the "optical" picture and the "liquid drop" model; the size and shape of the nucleus; high energy radiations, as tools for nuclear studies; prospects of a theory of nuclear forces.

The Effects of Irradiation on the Physical Properties of Solids *by Dr. A. H. Cottrell (Atomic Energy Research Establishment, Harwell).*

Ionizing radiations dissipate most of their energy in solids by ionizing and exciting electrons. Severe radiation damage is produced in organic and ionic substances by this process, but in metals the flexibility of the free electron structure confers substantial immunity to ionization damage. Atoms in metals are displaced by collisions with fast particles and the point defects so created alter the electrical conductivity and other physical properties of metals. These point defects interact strongly with dislocations, with the result that the mechanical properties of metals are very sensitive at low temperatures to heavy-particle bombardment. In semiconductors the displaced atoms can trap conduction electrons and so produce large changes in electrical properties. Very intense particle bombardment produces drastic effects. Some minerals become non-crystalline; uranium crystals change their shape markedly; and rare gas atoms created by transmutations within the material may cause disintegration in brittle crystals and swelling in ductile ones.

Shielding for Reactors *by Dr. G. C. Laurence (Atomic Energy of Canada Limited, Chalk River).*

A brief general discussion is given of the design of shielding for nuclear reactors. It includes consideration of design requirements, choice of materials and dimensions, nuclear reactions that affect the penetration, and heating of the shielding. Because the basic data available are insufficient for high accuracy in design calculation, the use of very complex theory and very laborious calculation has little advantage. Approximate methods are used, and allowance made for possible error in calculating the thickness of shielding required. These approximations are discussed. The problem is simplified by neglecting radiation processes that have relatively little effect on the over-all penetration, but the importance of these effects depends on the design of the shielding. This question is discussed.

The Control of Reactors *by Dr. A. J. Salmon (Associated Electrical Industries Ltd. Research Laboratory).*

The concepts of reactivity, neutron lifetime and delayed neutrons are described and their relationships with the rate of change of neutron density and reactor power are discussed. The amounts of reactivity to be controlled in a reactor may be large and varying with time; the various components of this reactivity are noted and discussed.

The physical methods of control are surveyed and the safety of reactors is briefly considered.

The Instrumentation of Reactors *by W. Macrae (C. A. Parsons and Co., Ltd.).*

The paper presents a survey of the over-all instrumentation of reactors. All reactors produce power, their normal operating level ranging from the order of 1 W in so-called "zero energy" experi-

mental reactors to hundreds of megawatts in power reactors. It is with the measurement and control of this power and its effect on the temperature of the reactor components and coolant (if any) that most of the instrumentation of a reactor is concerned.

There are two main groups of instruments, those operated from detectors sensitive to neutron flux—flux measuring instruments—and those concerned with physical measurements such as temperature and coolant mass flow. The principles of operation of the various instruments are described and their relative importance under various operating conditions indicated. In power reactors, instruments are also necessary for the detection of faults in protective fuel containers. The principle on which such instruments can operate is described.

The paper concludes with an assessment of the instrument requirements for a large power producing reactor.

The Role of Chemistry in a Nuclear Energy Project *by Dr. R. Spence (Atomic Energy Research Establishment, Harwell).*

The development of atomic energy has been unique from a chemical point of view, in that a whole series of new elements, the actinide series, has been produced and some of these, such as neptunium, plutonium and americium, play a major role in the technology. Furthermore, many elements which were previously little known and of academic interest only, have become of technical importance in the project, as for example, ruthenium, zirconium and protactinium. All this has resulted in notable developments in the field of pure inorganic chemistry, especially of the heavy elements and the fission products.

Most industrial enterprises which require special materials and which involve chemical processes, are based on substantial development work in technical chemistry.

Atomic energy can be divided into the following broad fields, from this point of view, viz., raw materials; production of fuel elements and other special reactor materials; reactor chemistry; chemical processing of irradiated materials; disposal and utilization of radioactive waste materials.

As the above classification indicates, technical chemistry has many ramifications in atomic energy. In the raw materials field the chemist and chemical engineer work in association with the geologist, mineralogist and ore dresser; in the production of fuel elements, they link up with the metallurgist; in reactor chemistry with the physicist, metallurgist and reactor engineer; in waste disposal with the radiobiologist, geologist and industrial user of radiation.

Although the provision of materials and the processing of irradiated fuel elements are of great importance, the nuclear reactor itself has always been the centre of interest. The earlier forms of reactor did not in themselves present any very serious chemical problems. Newer forms of reactor, however, operate at high temperatures and frequently bear more resemblance to chemical or metallurgical plants than they do to mechanical apparatus. There seems little doubt, therefore, that the chemist will be involved equally with the physicist, metallurgist and engineer in the future development of nuclear reactors for power.

The Role of Metallurgy in a Nuclear Energy Project *by L. Rotherham (Industrial Group Headquarters, U.K. Atomic Energy Authority, Risley).*

The development of nuclear energy both for weapons and more particularly for peaceful applications is essentially a new branch of applied science. Like many new engineering projects some of the limitations to future progress depend on metallurgical difficulties.

Problems arising in the construction of the large chemical plants for any nuclear power project are essentially the same in kind, although perhaps rather more acute in character, as those in normal chemical industry where dangerous and toxic chemicals are involved.

On the other hand, the manufacture of fuels for nuclear reactors has required a new industry to be set up for the extraction of uranium, and other new metals are becoming increasingly important if progress is not to be retarded. Apart from new metals, new alloys and higher quality material in conventional metals have been required for the protection of uranium from attack by the coolants used. From the earliest days this has been one of the acute problems of nuclear energy.

Finally the metallurgical problem peculiar to atomic energy is the development of materials which will withstand the effects of neutron irradiation. The effects on non-fissile materials are usually minor changes in physical properties, but on fissile material the effects are much more severe. At lower temperatures the anisotropic nature of uranium results in large dimensional changes which are being overcome by grain refinement techniques involving alloying and heat treatment. At high temperatures the gaseous fission products tend to expand and disrupt the material by mechanisms which are not yet fully understood, and for which cures are still being developed.

The Canadian Research Reactors and their Uses *by Dr. W. B. Lewis (Atomic Energy of Canada Ltd., Chalk River).*

The heart of the programme at Chalk River is the high-flux, heavy-water-moderated NRX reactor. The primary aim justifying this and the even more costly NRU reactor is to explore the possibilities of deriving low-cost electricity from nuclear energy. This aim is not, however, pursued narrowly and the reactors are used to foster basic research in nuclear physics, nuclear chemistry, radiation physics, chemistry and biology. Since separated fissile material has high intrinsic value in atomic energy research, emphasis has been and still is given to the production of plutonium and uranium-233 as well as to certain radio-isotopes, tritium and cobalt among others.

Nuclear power will become important within Canada only if it is cheaper than power from the present-day alternatives. The more costly of these are coal in Ontario, coal and oil in the Maritime Provinces, and oil in remote industrial installations such as mines and wood-pulp mills. Coal in Ontario at $8/ton and contributing 3 mills/kWh to the cost of electricity, sets the major target. Results obtained in the NRX reactor indicate that once the large development costs have been worked off nuclear power costs will be definitely lower than this target.

Canada is relatively rich in uranium and must immediately consider the particular requirements of foreign as well as domestic consumers. Consequently the research remains broad, and very full programmes lie ahead, not only for the NRX reactor, but also for ZEEP which is mostly used for measurements on fuel arrangements, and a proposed PTR (swimming-pool test reactor) which will take over the function of ZEEP for measuring reactivity effects of materials, particularly after irradiation. The most powerful and versatile research reactor is, however, the NRU, a heavy-water-cooled and moderated, high-flux reactor, which should be in operation in 1956.

The United Kingdom Research Reactors and Their Uses *by F. W. Fenning (Atomic Energy Research Establishment, Harwell).*

A brief description is given of the U.K. research reactors. Five are in operation at present and four more are in process of being constructed. They are:

(1) GLEEP, a low flux natural uranium graphite-moderated reactor,
(2) BEPO, a medium flux natural uranium graphite-moderated reactor,
(3) DIMPLE, a low flux heavy-water-moderated reactor, designed to take a variety of core arrangements.

The remaining two reactors already operating are fast reactors. These are:

(4) ZEPHYR, a plutonium fuelled reactor and
(5) ZEUS, a uranium-235 fuelled reactor.

The four reactors being built are all thermal reactors. Three use heavy-water moderation, and are designed to give a flux of 10^{14} n/cm^2-sec. The fourth is natural-water moderated of the "swimming-pool" type, and should give a flux of 10^{12} n/cm^2-sec. These four reactors will all be fuelled with uranium-235.

The uses of these reactors are listed and a description of some of the more important uses is presented. The low heat output reactors are primarily used for tests related to particular designs of reactor which are being considered as power units. However, some basic neutron physics studies are also carried out.

The higher heat output reactors are valuable sources of neutrons and γ-rays. For basic physics studies of interaction of neutrons with materials, beams of neutrons emerging from holes in the reactor shield are used in scattering and transmission studies. In solid state physics, the effect of fast neutron irradiations on crystal structure is studied by irradiations of materials inside the reactor and measurement of various physical properties either during or after irradiation.

The effect of radiation on chemical reactions is also receiving considerable attention.

Books

Peaceful Use of Atomic Energy (*A United Nations publication, available H.M. Stationery Office,* 1956, 16 *Vol., averaging* 550 *pages each, cost per vol. ranging from* 36*s. to* 70*s., complete set* £46).

All these volumes of the proceedings of the International Conference in Geneva, August, 1955, are now available. The individual books contain the original papers presented at the Conference, followed by a verbatim report of the discussions. In many instances this may appear to be unnecessarily lengthy but the aim has been to produce a complete record of the Conference without editorial comment. The sub-division into volumes in some instances is a little arbitrary but this has been caused largely by the general nature of the papers and the main theme of the contributions has been the deciding factor.

Particularly in papers from the United Kingdom and the U.S.S.R. a greater attention to detail would have been desirable and also more contributions from industry would have given a clearer picture of the British programme. Nevertheless, these volumes must rank as one of the main sources of information for coming scientists and engineers for many years.

The complete series is as follows:—

Volume
1 The World's Requirements for Energy; The Role of Nuclear Power. 57s.
2 Physics; Research Reactors. 57s.
3 Power Reactors. 54s.
4 Cross Sections Important to Reactor Design. 54s.
5 Physics of Reactor Design. 63s.
6 Geology of Uranium and Thorium. 63s.
7 Nuclear Chemistry and the Effects of Irradiation. 70s.
8 Production Technology of the Materials Used for Nuclear Energy. 70s.
9 Reactor Technology and Chemical Processing. 70s.
10 Radioactive Isotopes and Nuclear Radiations in Medicine. 57s.
11 Biological Effects of Radiation. 57s.
12 Radioactive Isotopes and Ionizing Radiations in Agriculture, Physiology, and Biochemistry. 63s.
13 Legal, Administrative, Health and Safety Aspects of Large-Scale Use of Nuclear Energy. 50s.
14 General Aspects of the Use of Radioactive Isotopes; Dosimetry. 45s.
15 Applications of Radioactive Isotopes and Fission Products in Research and Industry. 54s.
16 Record of the Conference. 36s.

Control of Nuclear Reactors and Power Plants *by M. A. Schultz* (*McGraw-Hill Book Co. Inc., New York,* 1955, *viii* + 313 *pages,* $7.50).

The book is the first aimed at presenting a comprehensive account of the theoretical considerations and philosophy common to the various types of reactor control systems. There is a considerable difference between the control systems now in use on various reactors but many of their basic features are identical.

The physics of the control process is discussed taking into account the temperature coefficient of reactivity, fission product poisoning, etc., and is followed by a chapter on reactor kinetics. Succeeding chapters deal with automatic reactor control, reactor control mechanisms, nuclear power plant control and reactor control radiation detectors. Operational control problems are dealt with, under the headings of start-up, power operation and shut down, and the concluding chapter deals with types of simulators that have been built to study techniques of reactor operation.

The volume will undoubtedly be read by most engineers concerned with nuclear plant whether for small experimental reactors or large-scale power stations and, although detailed mechanisms are liable to develop considerably over the next few years the basic problems outlined will remain the same.

The book is attractively presented and printing and paper quality are excellent.

Introduction to Atomic Physics *by S. Tolansky* (*Longmans Green and Co., London, 4th Edition,* 1955. *XIII* + 435 *pages.* 25s.).

The book is based on the course given to the second-year physics students at Manchester University. It has been produced in a new edition to accommodate some of the more recent discoveries in fundamental physics but retains the approach of taking the student through the historical derivation of modern theories. Four new chapters have been added in this edition, dealing respectively with the recent methods developed for detecting single particles, the properties of mesons, the high energy particle accelerators and the various nuclear reactors. The chapter on cosmic rays has been enlarged and a new section has been added dealing with radioisotopes. The book is fully illustrated with drawings, graphs and plates and although the book is primarily designed as a text-book for the student doing an honours physics course engineers will find in its pages a valuable introduction to the physics involved in reactor engineering up to the stage but not including neutron diffusion theory. A minimum of mathematical analysis is included and even the chapter on wave mechanics is readily understood.

correspondence

The A.M.F.—Mitchell Reactor

Sir,

The article in your June number on the A.M.F.-Mitchell Reactor was intriguing in many ways but it gave no clear indication of the actual status of the project. Does this constitute a complete and fully developed design worked out to the last degree of engineering detail, or is it simply a paper design study? One would also like to ask the author what arrangements have been made for the construction of an actual prototype reactor, what is the capital cost of the plant, how much U 235 is required for the core, and what are the over-all economics of the scheme including the actual fuel cost.

The idea of a self-contained natural-circulation primary cooling system is certainly attractive. It would be of great interest, however, if the author could give some detailed information about the consequences of a serious fuel element failure. Assuming that disintegration of a fuel element occurred, with the resulting release of fission products and uranium into the primary water circuit, what would be the level of activity at the heat exchanger? The fuel element handling system has the merit of extreme simplicity, but it is evidently envisaged that the changing of fuel elements would be a special operation to be carried out only at approximately yearly intervals by a visiting team of specially trained men. Is there any provision in the design for the detection of a faulty fuel element and for the removal of such an element before deterioration could lead to the contamination of the whole primary circuit?

A. S. Robinson.

Radio-isotopes by Post

Sir,

We wish to draw your attention to the conditions laid down in the Post Office guide on pages 55-56 concerning the maximum permissible levels of radiation from packages for postal transportation. The appropriate paragraph concludes ". . . that when made up for the post the radiation measured at the outside surface of a package does not exceed ten millirontgen per twenty-four hours. Containers and receptacles should be submitted to the Postal Services Department (HMB) Headquarters Building, St. Martin's-le-Grand, London, E.C.1, in order to ascertain whether they are regarded as suitable."

C. F. Payne,
G.P.O. Postal Services Department.

Dosemeter Terminology

Sir,

Knowing how strictly you keep to your house rules regarding the wording of technical articles, I wonder if you could institute a house rule for *Nuclear Engineering* to use the word 'dosemeter' (three syllables) instead of 'dosimeter' (four syllables). I notice that the otherwise excellent article on Portable Radiation Monitors was full of the word 'dosimeter.'

J. S. Blair.

Sir,

I agree with your correspondent about the use of the word 'dosemeter' rather than 'dosimeter.' In many of my papers I have used the former wording, but it should be noted that the Services in this country, including the Home Office Civil Defence Department, have chosen to use the word 'dosimeter.' This is in line with the policy of the American Services. However, I agree that the spelling of 'dosemeter' is preferable and I would advocate that this spelling be adopted by *Nuclear Engineering* in the future.

Denis Taylor.

Correspondence should be addressed to the Editor, *Nuclear Engineering,* Temple Press Limited, Bowling Green Lane, London, E.C.1.

Processes and Equipment

New Laboratory Oscilloscope

The Mullard L.140 laboratory oscilloscope has a highly linear triggered time-base with a large range of sweep durations, and a wide band Y amplifier. A new circuit has been developed which ensures time-base linearity, especially at the start of the sweep. This feature, together with the signal delay circuit, makes possible the accurate investigation of the complete leading edges of pulses.

Time base sweep durations are from 1 microsec. to 150 millisec. and a sweep expansion circuit continuously variable from 1 to 5 diameters can be used to expand the trace horizontally about the tube centre. When used in conjunction with the X shift controls, this allows minute examination of any part of the trace.

Triggering can be either internal by the displayed waveform, or external from a separate source of trigger voltage. With internal triggering, a sensitivity control allows sweep initiation at Y input levels corresponding to trace deflections down to 3 mm.

Nine sensitivity settings ranging from 3 mV per cm. to 30 V per cm. are provided. The amplifier is directly coupled on the lower gain settings (100 mV per cm. and over), and has a rise time of 0.07 microsec. On the high-gain settings the rise time is 0.08 microsec. Pulse amplitude can be measured to better than 3% (low gain 0.3 V-300 V) or 4% (high gain, 10 mV-1 V).

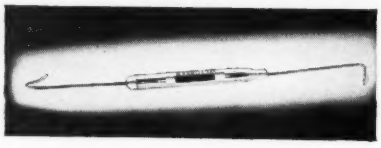
The cathode follower probe has a high input impedance and gives an output which is linear to within 0.25% for signal voltages from −150 V to +150 V.

The Mullard L.140 laboratory oscilloscope incorporates circuits specially designed to make possible the accurate investigation of the complete leading edges of pulses.

Wire Belt Slings

A new type of crane sling which is particularly useful for handling cylindrical objects is now being made by the British Wedge Wire Co. Ltd., Academy Street, Warrington. In belt form, the sling is of transverse looped wire construction and fully articulated so that kinking or tangling cannot occur. The design also gives a good gripping action so that there is little danger of a load slipping.

The slings are made in widths of 3 in., 5 in., 8 in., 10 in., 12 in. and 18 in. with safe working loads ranging from 1 ton to 7½ tons for choke hitch or straight pull, and from 2 tons to 15 tons with basket hitch. These loads are one-fifth of the sling breaking load. The standard range uses heavy duty 10 S.W.G. steel wire fabric, but slings in different meshes and materials can be supplied.



A Victoreen glass-sealed deposited-carbon resistor.

Resistors and Voltage Regulators

The range of Victoreen glass-sealed deposited carbon resistors, Hi-Meg resistors, and voltage regulators made by the Victoreen Instrument Co., 3800 Perkins Avenue, Cleveland, Ohio, is handled in Britain by Anglo-Netherlands Technical Exchange Ltd., 3 Tower Hill, London, E.C.3.

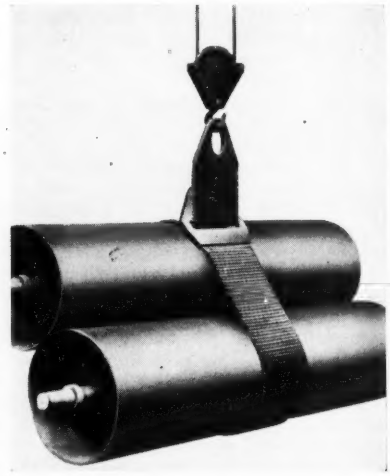
The resistors use a ceramic rod element with deposited crystalline carbon and sealed in glass envelopes containing an inert gas. The 29 standard voltage regulators have nominal operating voltages ranging from 57 to 27,000.

Aluminium-Alloy Busbars

A new aluminium alloy for busbars has been developed by the Northern Aluminium Co. Ltd., Banbury, Oxfordshire. Known as Noral D50S, it has been designed to give the best possible combination of mechanical strength and electrical conductivity at low cost.

Its minimum ultimate tensile strength is 13 tons per sq. in. (minimum 0.1% proof stress, 10.5 tons per sq. in.) and its electrical resistivity is 3.133 microhm per cm at 20°C (55% I.A.C.S.). Being a fully heat-treated magnesium silicide alloy its conductivity is lower than that of electrical-purity aluminium. Its temperature coefficient of resistance (0.00364/°C), however, is lower: this, to some extent, offsets the lower conductivity.

Noral D50S is available in extruded sections or, if required, in plate form.



The Wedco wire belt sling provides excellent load balance and gripping power and is especially suitable for handling cylindrical objects.

Aluminium Soldering Flux

Hyflux-Al flux has been specially developed for use in the soldering of aluminium and its alloys. It is a powerful flux, based on hydrazine, and permits soldering without any previous roughening of the metal surface. It rapidly attacks and removes oxide film and protects the exposed metal from further oxidation before the molten solder has spread over it. The flux volatilizes after a short period at soldering temperatures leaving no residue around the joint.

The flux works with any of the recognized solders used for aluminium, the recommended working temperature being around 280°C, but not above 300°C. The solder used should be one that spreads easily at about 10°C lower. The fumes from the hot flux are somewhat toxic and adequate ventilation should be provided especially if working in confined areas.

The makers are Whiffen and Sons Ltd., North West House, Marylebone Road, London, N.W.1.

Spot Welder

The latest addition to the range of Quasi-Arc Sigma equipment is a spot welder giving high production rates—up to 20 spot welds per minute including positioning and post-weld shielding. Mild steel, stainless steel, and copper-based alloys can be spot or plug welded up to ¼-in. thickness and, as the weld area is shielded by inert gas, the weld is free from oxide inclusion and has a smooth clean surface.

The process is automatically controlled. Welding is from one side only and no forging pressure is needed. Filler wire is automatically fed into the weld pool and controlled so that sink holes are eliminated.

Made by Quasi-Arc Ltd., Bilston, Staffs, the machine can be quickly converted from spot to seam welding.

Photomultiplier Tube

A 10-stage ¾-in. photomultiplier tube with a rated average gain of 300,000 at 105 V per stage has been developed by Allen B. Du Mont Laboratories Inc., 750 Bloomfield Avenue, Clifton, New Jersey, U.S.A. Designed with potted base and jacketed leads to eliminate moisture leakage, the new tube will undoubtedly be applicable to oil and uranium prospecting. Used in clusters they can speed up diagnostic procedures in medical work.

At 105 V per stage the maximum dark current measures 0.1 microamp, photocathode sensitivity is 40 microamp. per lumen, and the average anode sensitivity is 12 amp. per lumen.

The new ¾-in. 10-stage Du Mont photomultiplier tube.

Automatic Argonaut Welding

The range of Argonaut welding equipment made by the British Oxygen Co. Ltd., Bridgewater House, Cleveland Row, London, S.W.1, has been augmented by automatic equipment.

Argonaut is an inert gas shielded electric welding process using a continuous consumable wire electrode and suitable for welding aluminium, stainless and mild steels and copper. The new automatic head provides for the production welding of heavy sections. It is designed to handle 600 amp. D.C. continuously and is usable with 0.035 in., 0.045 in., 1/16 in., 5/64 in., and 3/32 in. diameter "hard" wires, and 3/64 in., 1/16 in., 3/32 in. and 1/8 in. aluminium alloy and magnesium alloy wires. The unit consists of a welding head housing the wire feed mechanism, a water-cooled machine barrel, and reel-casing assembly, a wire casing, main control panel and remote control. The head maintains constant arc voltage by varying the speed of the wire feed. Two speed ranges are provided: 80-350 in./min. and 150-450 in./min. Special gears can be supplied to give speeds up to 750 in./min. if required. A slow wire down-feed control permits smooth arc starting, whilst a stub burn-off control eliminates freezing of the welding wire into the weld pool at the end of an operation.

The 600 amp. composite dry rectifier comprises a 3-phase transformer with primary tappings for 360, 380, 400, 420, and 440 V, and a dry-plate selenium-type fan cooled rectifier with automatic protection against fan motor failure.

Temperature Controller-Recorder

The Transitrol indicating temperature controller is a new direct deflection instrument operating on a principle which utilizes a resistor, thus eliminating the need for thermionic valves, magnetic amplifiers and oscillator circuits. Moving parts require no lubrication or adjustment.

The instrument incorporates a conventional galvanometer used as the measuring system, and an indicating pointer operating a simple photo-electric system which, in turn, controls the heating medium.

The control arm is adjustable externally to the temperature set-point and is fitted with photo-sensitive transistor optical lens and low-level light source. When the transistor receives full illumination a relay is energized, giving external switching control. The pointer is fitted with a flag which passes freely between the light source and the transistor. When the desired temperature is reached, the light source is cut off from the resistor, thus de-energizing the control relay and shutting off the heating medium. Full compensation is provided for cold-function variation and copper temperature coefficient.

The instrument is designed as a plug-in unit and has a scale length of 6.5 in., the calibrated accuracy being ±1%.

The makers are Ether Ltd, 60 Tyburn Road, Erdington, Birmingham 24.

Vacuum Shelf Drier

A new type of vacuum shelf drier suitable for the treatment of delicate materials which are sensitive to heat and oxidation and which need uniform low-temperature drying has been developed by Calmic Engineering Co. Ltd., Crewe, Cheshire.

It is a characteristic feature of this A.L.A. system that the material to be treated is placed on jacketed trays into which sub-atmospheric steam is introduced. At 30 mm Hg absolute—the normal working vacuum of the oven—the temperature in the trays can be as low as 25°C, although for practical purposes it is about 35°C. The method allows rapid even drying, giving about 2 in./sq. ft./hr. evaporation with water only and an efficiency figure of between 1.1 and 1.3 lb. steam per lb. moisture evaporated.

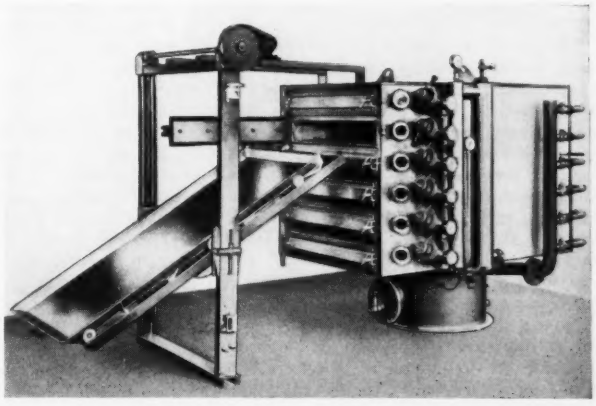
The area of a tray is 18 sq. ft. (approximately 3 ft. × 6 ft.) and models are available with one, two, three, four, five or six trays per machine. Furthermore, the A.L.A. system is available in two types: (a) as a continuous-working drier in which each tray is contained in a separate drying cell; and (b) as a chamber drier in which a number of trays are contained in one or more chambers. As each cell works as a separate unit in the continuous-working model, any tray may be loaded and emptied without interrupting the drying process in the others. A simple elevating table, with a tilting device, facilitates the handling of trays.

The A.L.A. shelf drier is supplied complete with steam converter, elevator, and all necessary gauges and valves. Automatic temperature control can be provided. The chambers and cells can be of ordinary, stainless or acid-resistant steel.

Vacuum pumps, of both reciprocating and water-ring types, suitable for use with the driers, are available. The 70 c.f.m. capacity reciprocating pump can be used with two six-tray driers with a maximum vacuum of 30 mm Hg. The casing is of cast iron with piston rod of chrome nickel steel or with piston, piston rod, valve covers and cylinder liners of acid-resisting bronze. The pump requires at least 1½ g.p.m. water for lubrication and sealing.

The 56 c.f.m. two-stage water-ring pump will operate with a drier up to the six-tray size at 20 mm Hg maximum vacuum. The pump needs a minimum of 3 g.p.m. water to maintain the water ring. Two models are made: one with cast-iron casing and rotor and stainless-steel shaft, and the other of acid-resisting bronze with stainless-steel shaft.

Calmic Ltd. also make a small pilot-scale drier with a single jacketed tray of 3 sq. ft., vacuum driers of the hot air, water or hot-oil circulating types and freeze driers to customers' orders.



A six-tray single-chamber type A.L.A. vacuum drier made by Calmic Engineering Co. Ltd. Each jacketed tray has an area of 18 sq. ft.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. each (including postage).

B.P. 749,762. Recovery of uranium by ion-exchange. T. V. Arden. To: Permutit Co. Ltd.

This refers to the recovery of complex uranium anions from a resin containing diethylamine or dimethylamine groups, or any other resin of equivalent basicity, which has been used to take up both uranium and iron as complex anions from a given sulphate solution obtained by treating ores with sulphuric acid. The resin is treated with dilute sulphuric acid or a dilute solution of a neutral metallic sulphate (or mixture). It is found that the iron is then removed selectively (preferentially to the uranium). The uranium is eluted from the resin and obtained uncontaminated by iron.

B.P. 750,328. Gamma-ray thickness gauges. J. L. Putnam, S. Jefferson, R. B. Owen. To: U.K. Atomic Energy Authority.

The gauge operates on the back-scatter principle to measure thickness—of the wall of a pipe, for example—from the outside surface only. The source of gamma rays (a needle of cobalt-60 protected by a thin brass tube) is placed within about 0.02 in. of the surface and the detector is also placed so close to the surface that no shielding is required to protect the operator. The detector (scintillation counter) is exposed to direct radiation from the source and to gamma rays back-scattered through that surface area. The back-scattered rays received by the detector produce pulses of an amplitude range distinct from those produced by direct excitation. They are segregated by a pulse amplitude analyser. The pulse rate produced by direct excitation is a constant of a given source strength. The adjustment of the zero reading will be effected for a predetermined background count when no workpiece is present so as to obtain direct thickness readings.

B.P. 751,429. Nuclear reactor. To: Stichting voor Fundamenteel Onderzoek der Materie (Netherlands).

The specification refers to a heavy-water-moderated reactor producing thermal energy by circulating a coolant through reactor and heat exchanger. In such reactors, the coolant may be a separate liquid flowing around the spaces containing the nuclear fuel, or the nuclear fuel itself circulates in the form of a solution, or of a suspension in a carrier fluid through reactor and heat exchanger. The heavy water may simultaneously act as moderator and carrier fluid and may transfer the thermal energy as already outlined.

Now if the heat generated is to be used for driving steam turbines it is important that the thermal energy be delivered at a high temperature level. In that case boiling of the liquid must be prevented by keeping the pressure high enough. The practical temperature limit for H_2O or D_2O is about 300°C corresponding to 80 atm. but it is impossible to install pipes or vessels capable of withstanding such pressures inside the reactor. The wall thickness would have to be so great that a chain reaction could be maintained only with highly enriched nuclear fuel. The problem has been solved by building the entire reactor, including at least a substantial part of the reflector into a pressure-proof steel vessel, to which pressure-proof conduits for the liquid to be circulated through the reactor are connected. If the nuclear fuel is suspended in only part of the total quantity of heavy water and the rest of the heavy water passed through the reactor through a separate circuit, then the moderator may be kept at a low temperature, whereas in the suspension high temperatures may be tolerated. The pressure casing may at the same time serve as an absorption agent for gamma radiation and therefore the concrete shielding need not be so thick. If a fuel suspension and the liquid moderator are circulated through the reactor the partition walls may be of tightly sintered BeO with minimum neutron absorption; BeO may also be used as the reflector material instead of graphite. Control may be exercised in known manner (by varying water level; by rods of neutron-absorbing substance). If part of the reflecting material is arranged outside the pressure casing, control is effected by moving that part of the reflector and interposing a body of neutron-absorbing material. Automatic precision control is also possible with heavy water as moderator because the moderating properties of heavy water decrease with increasing temperature.

B.P. 751,477. Pressure vessels to which tubes are to be sealed. H. Harris. To: Babcock and Wilcox Ltd.

The wall thickness and the composition of the metal of the pressure vessel (vapour generator) lead to the problem of making a pressure-tight weld between tube and vessel; the usual mechanical seal by expanding the tube ends is not applicable due to the difficulties of displacing such thicknesses of metal. The vessel is of a metal the hardness of which is increased by heating to critical temperature and subsequent cooling. The welding operation must be carried out without heating the metal of the vessel above its lower critical temperature. This is achieved by providing around the tube seat a lamina of metal in the shape of a ring welded in position which is unaffected by heating and cooling consequent on a fusion welding operation and of such a size that a seal weld can be formed between the lamina and the tube and without bringing that portion of the vessel adjoining the lamina to the critical temperature. The metal of the lamina may be mild steel or commercially pure iron. (add. to: 713,054).

B.P. 751,700. Nuclear reactor. To: Stichting voor Fundamenteel Onderzoek der Materie (Netherlands).

This refers to a reactor of small critical dimensions with ordinary or heavy water as the moderator, or in which enriched uranium is employed. The electromagnetic radiation amounts to about 5% of the total energy produced in the reactor and has to be absorbed in the concrete shield. Difficulties are encountered, especially in the case of the supply of large quantities of thermal energy, by local overheating of the concrete mass of low thermal conductivity which may result in undue stresses, and even in disintegration of the concrete. Adequate cooling of the concrete shield leads to difficulties in practice. These obstacles can be overcome by making the protecting shield of bismuth or a bismuth compound and by providing such a shield with means for carrying off the heat produced therein. Such a reactor is many times smaller than the concrete-shielded reactors known hitherto. Bismuth or a bismuth compound may also be used as reflector material in view of the low effective neutron capture cross-section and the high effective neutron scattering cross-section of bismuth atoms. The reflector and shield can be constructed as an integral unit. Metallic bismuth combines maximum effectiveness with minimum volume.

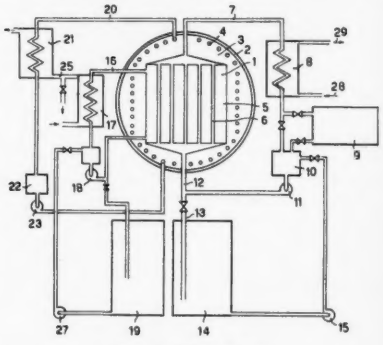


Fig. 1. B.P.751,700.

The illustration shows reactor (1) enclosed by steel casing (2) surrounding bismuth jacket (3), with the cooling tubes (4). A suspension of uranium in heavy water is circulated through a system of tubes (6) of low neutron absorption and low heat conductivity made with a thin BeO wall coated towards space (5) with a loosely sintered BeO layer. The heat exchanger (8) transmits the heat to water supplied through pipe (28) and discharged through pipe (29). The suspension returns through (10), (11) and (12) to tube system (6). The heavy water circulates through space (5) and heat exchanger (17) and returns through pump (18). Tube system (4) lies in a cooling circuit including heat exchanger (21) and pump (23). The heat exchangers (21) and (17) are connected so as to use part of the coolant passing (17) for cooling the medium carrying off heat from the bismuth jacket (3).